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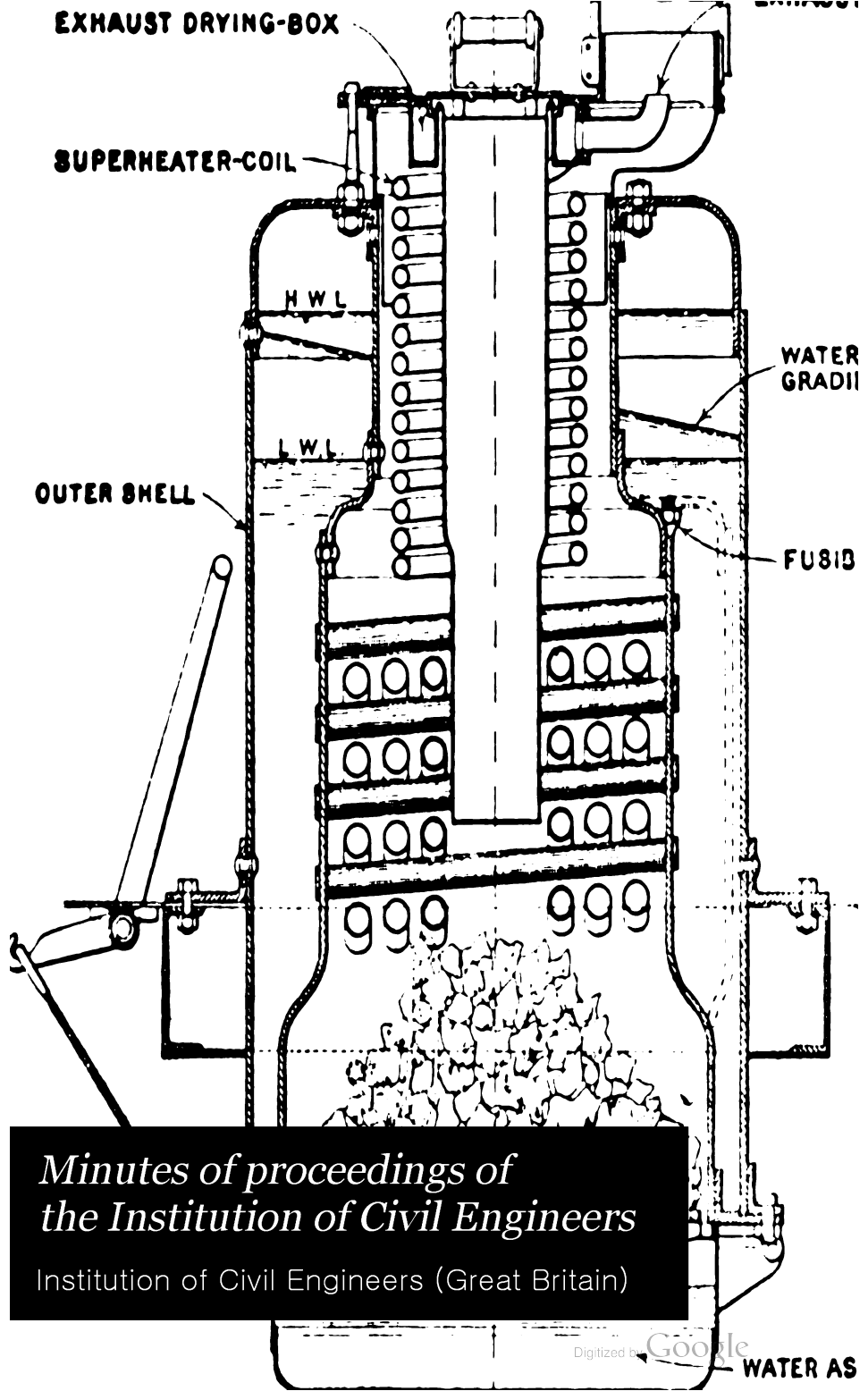

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Institution of Civil Engineers (Great Britain)

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INDEXED.

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CLXIX.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1906–1907.—PART III.

SECT. I.—MINUTES OF PROCEEDINGS.

5 February, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

The Council reported that they had recently transferred to the class of

Members.

WILLIAM HENN HINDE. | JOHN ALEXANDER LORIMER.
JAMES WILMOT ANDREAS ROSE.

And had admitted as

Students.

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JOHN HUNTER CAMERON.
HERBERT THOMAS CHIDGEY.
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CHARLES BOTHAM WHITE.

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Associate.

OSWALD JOHN MANSON.

(*Paper No. 3669.*)

"Modern Motor-Vehicles."

By Lt.-Col. ROOKES EVELYN BELL CROMPTON, C.B., M. Inst. C.E.

PART I.—PRINCIPLES OF DESIGN AND CONSTRUCTION.

THE invasion of the roads and streets by the motor-car, motor-van, and motor-omnibus has already become of such interest to the general public that not only do most journals devote a daily column to motoring matters, but, in addition, the interest shown by owners and users of these vehicles in the technical matters connected with their construction and working has brought into being fourteen technical or semi-technical journals, all of which

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seem to be well supported. The existing literature is therefore abundant, and renders it unnecessary for the Author to encumber this communication with a mass of descriptive matter which is so easily accessible to those who wish to study it closely.

To give some idea of the importance and rapid growth of this new industry, it has been stated that, although the total number of mechanically-propelled vehicles used in England for commercial purposes is probably rather less than 10,000, the rate of output of these vehicles reached, in 1905, 3,500 per annum, valued at £1,250,000, and is still increasing rapidly: while the number and value of motor-cars used for pleasure is probably much larger. In the latter case, however, the proportion of imported vehicles is much larger than in the case of commercial vehicles.

In this Paper, in order that sufficient attention may be devoted to discussing that side of the subject which appeals particularly to engineers, the Author has curtailed the historical treatment of the matter, and has confined his descriptions of existing vehicles to a number of examples of typical systems sufficient to illustrate the present state of their development. These descriptions, with particulars of the working-cost of various vehicles, form Part II of the Paper (pp. 43–64).

It must not be forgotten that the road-locomotive came before the railway-locomotive, and that English engineers, such as Hancock, Gurney and others, brought this engine to an advanced stage between 1820 and 1835. It is abundantly evident that at that time designers possessed far greater mechanical skill than has been generally credited to them, and that they had, during the short period that their vehicles were allowed to run on the road, successfully encountered many of the difficulties which will be discussed in this Paper; further, that the use of these road-locomotives was discontinued not on account of mechanical defects, as has been too commonly supposed to be the case, but solely on account of the interference of conflicting interests, which were successful in driving the vehicles off the road. If this had not been the case, and if the work of developing road-locomotion had gone on uninterruptedly, the present stage of development would most likely have been reached 50 years ago, and probably this would have had important effects on transportation generally, as it is quite possible that the facilities for the transportation of goods and passengers which can be afforded by a well-considered system of trunk railways, fed by motor-traffic over the roads, would have mitigated, if not entirely prevented, the reduction in land-values which has followed on the migration of the rural population into crowded towns. At any rate, during

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the 60 years which intervened between the days of Hancock and Daimler, the opinion that all transportation of goods and passengers must be effected on rails was so general that the attention of inventors was diverted from road-vehicles to the railways; and it was not until about the middle of this period that self-propelled engines began again to be used on the road, when agricultural engineers found it easy to make their portable thrashing-engines, and eventually their ploughing-engines, so that they could be self-propelled between points at which they were used for driving agricultural machinery.

About the middle of this period Fowler and others successfully worked out the problem of ploughing by steam, and then found it necessary to make the large engines which they used capable of propelling themselves not only from one farm to another over metalled roads, but also over the soft soil of the fields in which they worked.

It must be remembered that up to the year 1896, legislative enactments prevented road-vehicles from running at any speed exceeding 4 miles per hour. No inventor could test a passenger-vehicle on English roads, so that manufacturers of these vehicles were able to acquire experience only when they obtained orders for passenger-vehicles for service abroad; in this way alone was any further progress made with road-locomotion. The low-speed traction-engine, however, received close attention from several leading English agricultural engineering firms. By 1880 the majority of the portable engines used by farmers were traction-engines, and much experimental work was then carried out by the constructors of these engines. Many of the road-problems were then dealt with, so that some of the difficulties which modern constructors think they have met for the first time formed the subject of experimental research during the period between 1860 and 1890.

The new era of road-locomotion which will be discussed in this Paper may be said to have commenced with the invention, in 1885, of the Daimler motor, driven by petroleum-spirit: this engine required no boiler, and thus one great difficulty in the construction and working of road-carriages of small size was removed.

About this period the development of the safety-bicycle and its extended use by both sexes had developed a taste for touring on the roads of England and other countries. No doubt this had an important influence in creating a demand for greater touring-facilities, which was very satisfactorily met by the motor-car; so that Daimler and Benz in Germany, and Levassor, De Dion and others in France, found that a demand for touring-cars already existed,

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and that as soon as an easily-managed self-propelled pleasure-vehicle was procurable, the market for it was likely to be a large one.

In spite of the many defects of the early motor-cars, the output of these vehicles in France and Germany increased very rapidly, so that a sufficient number found their way into England to enable a relaxation of the legislative restrictions to be obtained from Parliament in 1896, in the form of the first Motor Car Act.

During the earlier period the interest shown in these vehicles was necessarily confined to the few enthusiasts who were sufficiently interested in mechanical matters, and were wealthy enough, to purchase and use them; but the pleasures of touring in a motor-car quickly became so infectious that the circle of buyers rapidly extended. The manufacture of motor-cars has now become an industry of national importance, and it is only fair that it should be publicly acknowledged that it is to these earlier buyers of pleasure-vehicles—which have so often been termed "rich men's hobbies"—that the present development is due, not only of the town and touring vehicle, but of the modern commercial van and omnibus, although the latter, and especially the heavier motor-wagons, owe much to the labours of the traction-engine designer of the last century.

General Arrangement of Mechanism.

The motor-vehicles now in use may be grouped in three classes:—

(1) Those driven by the internal-combustion engine, which for brevity may be called petrol-driven, and which at present form nine-tenths of the total number of lighter vehicles.

(2) Those driven by steam, which at present form only a small percentage of the lighter motor-cars, but the majority of the heavier vans and motor-wagons.

(3) Those driven electrically, of which a considerable number are in use within towns which have an electrical supply.

As already stated, most of the existing modern motor-vehicles are privately owned motor-cars which range from two-seated cars, having a single-cylinder engine of 4 H.P., to powerful cars with engines of up to 40 H.P., and capable of carrying five to ten persons.

It is unnecessary to discuss the bodies or coachwork of these private cars, and attention may be given forthwith to the part which contains the machinery. This framework, usually called a "chassis," is designed with considerable care, so as to obtain the requisite strength and rigidity with the minimum of material and weight. The chassis is in most cases mounted on four wheels which

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are generally of equal size, the wheel-diameters varying between 28 inches and 34 inches, and the wheel-base varying between 9 feet and 12 feet. The car is steered by the leading wheels being moved through the necessary horizontal angle by a steering-wheel, or in some cases by a tiller, connected by linkage on the Ackermann principle.

The engine which furnishes the motive power is mounted at the front end, the cylinders being vertical. The crank-shaft is longitudinal, in the centre line of the vehicle, and is coupled through a clutch to the propeller-shaft, which extends to and drives the back axle through bevel- or worm-gearing. This arrangement is called the live-axle drive. In another method of driving largely used, the right-angled change of direction is from the crank-shaft to a countershaft parallel with the back axle, the latter being driven from the countershaft by a pair of chains, one to each driving-wheel. In this case the back axle is fixed, and the arrangement is called the chain drive.

In petrol-driven cars a separate shaft with gear-wheels is interposed between the crank-shaft and the propeller-shaft, to enable the ratio of the gearing to be altered: with steam-cars this is unnecessary. With both classes of cars the differential gear, essential for road-vehicles, must be attached in the case of live axles to the live axle itself, but with countershafts it can be mounted on the countershaft.

This arrangement has been generally adopted for the following reasons. By placing the engine at the front end of the car with its crank-shaft longitudinal to the chassis, the designer can, if he desires it, modify the size and power of the engine by adding additional cylinders, as for this purpose it is only necessary to lengthen the chassis. The arrangement is also convenient, as it affords easy access to those parts of the internal-combustion engine which require most frequent attention, namely, the carburettor, the various valves, and the ignition-devices, all of which can be placed in convenient positions at the front end of the car, and close to the cylinder-heads.

The long wheel-base, which is such a distinctive feature of modern motor-cars, is the result of the demand for side entrances, as the entrance at the middle of the back rendered it necessary for passengers to step into the roadway instead of directly into their cars from the pavement.

The most important part of the modern petrol-car is the engine, which usually has one to four cylinders, although an increasing number of makers are using six cylinders for much of their output.

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The explosive mixture is supplied to the engine from a carburettor, which vaporizes the petroleum spirit and mixes it with its proper proportion of air to give the most efficient mixture. Then come the valves by which this mixture is admitted to the cylinders, the ignition-devices which are nowadays always worked by electrical means, and the cooling-apparatus for keeping the cylinder-heads containing the valves down to a safe working-temperature, which is almost invariably done by water-circulation, the water being cooled by being forced through a radiator placed right in front. The power from the crank-shaft is transmitted through a clutch, either direct to the propeller-shaft, or through an intermediate shaft when the gear-ratio has to be changed or the engine requires to be reversed. This change in gear-ratio is made by moving into mesh various gear-wheels, which are fitted to slide on the third shaft. This arrangement of the gear has been much varied in detail, but the main principles followed by the majority of designers remain the same as those introduced at a very early period by Messrs. Panhard and Levassor, the change-gears sliding into mesh in a direction parallel to the axis of the shafts carrying them.

In the case of a live-axle drive, the propeller-shaft drives the back axle through bevel-gearing, the bevel being fixed in a case which also contains the differential gear; but, quite recently, worm-gear of various types has come into use at this point, as it appears to be easier to keep this type of gear silent and efficient than is the case with the ordinary toothed bevel-gear.

When fixed back-axles are used with chains, the longitudinal drive of the crank-shaft is transmitted through bevel-gear to the countershaft, which is parallel to the back axle. A sprocket-chain pinion is provided at each end of the countershaft, and a further reduction in gear-ratio is provided by making these sprockets smaller than the chain-wheels on the driving-wheels. In the early days a good deal of the gear-reduction was made at this point; but, as it was found to be noisy and more bulky, chain reductions exceeding 3 to 1 are now uncommon.

A description of a typical petrol-driven private motor-car is given on p. 43, and is illustrated in Figs. 1, Plate 1, and *Figs. 1a* and *1b*, pp. 44 and 45. The approximate annual cost of upkeep of such a car is given in Table I, p. 59.

When steam is used as the driving-power of a private car, the arrangement of the petrol-driven car has been followed in some respects, the steam-engine and its boiler occupying the position of the internal-combustion engine, and the crank-shaft being longitudinal and driving the back axle direct through a bevel-gear. In other

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cases a countershaft and chains are used; but with steam, on account of its greater flexibility as a driving-power, there is no need for change-gear arrangements. The steam is condensed by being passed through a condenser fixed in the same position as the radiator of the petrol-car.

The chief feature which has made the modern steam-car possible has been the substitution of the flash-boiler or instantaneous generator (which requires no attention to be paid to its water-level) for the older type of boiler, which required very careful attention to water-level, and which from this cause gave trouble on the road whenever the water-supply was short or the water of bad quality. This instantaneous generator, although it was probably used by Hancock and Gurney, and again by Perkins, was re-invented in its present form by Mr. Serpollet, and possesses the great advantages of light weight and absence of danger from shortness of water. By providing a steady supply of superheated steam it has so greatly reduced the steam-consumption that it allows of considerable reductions in the size and weight of the generator itself, as well as of the engine, the condenser, and the other adjuncts. Since its adoption, the use of steam-cars has greatly increased in America and in England.

A typical form of steam-driven private motor-car is described on p. 46, and illustrated diagrammatically in Fig. 2, Plate 1. The approximate annual cost of upkeep is given in Table II, p. 60.

The general arrangement of electrically-driven cars differs notably from those of steam and petrol cars. In this case the motive power is derived from accumulators contained in a case, which must be placed low in the vehicle so that the accummulators can be readily drawn out to be changed or re-charged. The weight and position of this case of accumulators is the principal feature which governs the design of the car. The electric motor itself, on account of its strong starting-torque and its automatic adjustment of demand for electrical energy to the requirements of the road and speed, lends itself very conveniently to the driving of these vehicles, so that no change-gear is necessary.

In some cases one motor only is used, driving the rear wheels through differential gear; in other cases separate motors are fitted to each of the hind wheels, and in a few cases to each of the front wheels.

An electrically-driven cab of the latest form is illustrated in Figs. 3, Plate 1, and is described on p. 47. The approximate annual cost of upkeep is given in Table III, p. 60.

Although the cost and upkeep of the accumulators is at present

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the chief cause why the use of these cars is not spreading so rapidly as might have been expected, even in their present form they are undoubtedly excellent vehicles for town use. They are luxurious as carriages, work practically silently, are free from vibration and smell, can be pleasantly lighted direct from the accumulators, and require very little skill on the part of the driver, so that an ordinary coachman can work them after a very short training.

Turning to the heavier vehicles for public service and for commercial uses generally, although a good many of the smaller vans are driven by petrol, yet the larger vans, wagons, and tractors (of which so many are to be seen drawing trailer-wagons behind them in the streets of London) are steam-driven. The designers of the motor-omnibuses, of which there are already upwards of 700 in use in London, have, up to the present, followed the same general lines as those of the private motor-car above described: the engine is placed in front, and the live-axle and chain drives are used in about equal numbers. The principal organs are practically the same as those of the petrol-car, and will receive special attention later on, when the advantages and defects of certain component parts are considered.

A chassis for such an omnibus is illustrated in Figs. 4, Plate 1, and is described on p. 48, and this type of chassis may also be taken as fairly illustrative of that required for a 3-ton petrol-lorry intended to carry a weight of 3 to 5 tons. Approximate annual working-costs of motor-omnibuses in London and in the country respectively are given in Tables IVA and IVB, p. 61, and of a petrol-driven motor-lorry, which has a practically identical chassis, in Table V, p. 62.

At first designers thought that the power of engines of motor-omnibuses need not exceed 25 HP., but in recent designs with petrol-engines it is found necessary to give at least 40 HP., and steam-engine designers arrange in their vehicles that the same effort can be obtained when required. The weight of the chassis and body is limited in London to about 4 tons, of which 1 ton may be said to be that of the coachwork itself, leaving 3 tons for the chassis and machinery fully loaded with fuel and stores. The standard load is thirty-four passengers, sixteen being carried inside and eighteen outside.

Steam-driven omnibuses of the same size and capacity, although up to the present not so numerous as the petrol-driven omnibuses, have given such good results in respect of ample power, silent running, freedom from smell and vibration, and economy of maintenance, that the opinion is generally held that in the future

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a large increase in the number of steam-driven omnibuses will be seen.

The chassis for this type of omnibus is illustrated in Figs. 5, Plate 1, and *Fig. 5a*, p. 50, and is described at p. 49.

In the large class of motor-wagons which carry 3 to 5 tons and in some cases draw a trailer, steam practically reigns supreme. These motor-wagons are a peculiarly English development. At the time when France and Germany were very far ahead of England in the production of motor-cars, English designers had already made considerable progress with the motor-wagon, and this lead they have consistently maintained. The Author believes that this was largely due to the stimulus given to this branch of the industry by the series of trials carried out for 3 years in succession in the Liverpool district by the Self-Propelled Traffic Association. Many valuable data were then got together; and makers profited by them to such an extent that the motor-wagon industry in England is decidedly in advance of that in other countries. From an engineer's point of view this type is an extremely interesting one, as the degree of its success will greatly influence its adoption as the collector of goods for the railways. Moreover, the patterns in use show much greater divergence and originality in design than has been exhibited in the private motor-car. In these wagons, up to the present, boilers of the older type have been used, special means for superheating the steam being provided in some cases.

Three representative types of these vehicles are illustrated in Plate 2, and described in Part II of this Paper. They differ rather widely in design. The first, described on p. 51, and illustrated in Figs. 6, Plate 2, has evidently had its parentage in traction-engine practice. A small locomotive-boiler is fixed at the leading end, which carries a horizontal compound engine whose power is transmitted from a single driving-chain to the back axle.

The kind of steam-wagon described on p. 52 and illustrated in Figs. 7, Plate 2, is very commonly seen in the streets.

The working-cost of motor-wagons of the kind illustrated in Figs. 6 and 7 is given in Table VI, p. 62.

The third type, described on p. 53, and illustrated in Figs. 8, Plate 2, and *Figs. 8a–8e*, pp. 54 to 57, represents very recent practice. The vertical boiler, provided with means of producing highly superheated steam, is placed in front. The engine is placed horizontally underneath the wagon and has a pair of horizontal cylinders of large size; the crank-axle is geared at one reduction, at the low rate of three to one, direct to the back axle. This type has shown remarkable economy in working; its radius of action with

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one charge of fuel and water is very large. The working-cost is given in Table VII, p. 63.

The latest practice in traction-engine design is exemplified by the engine which is described on p. 58 and illustrated in Figs. 9, Plate 3. It is a compound spring-mounted heavy road-locomotive; and whenever sufficient load can be obtained to develop its full power, road-haulage can be carried out by it at the minimum cost per net ton-mile. The cost of hauling goods by heavy traction-engines of this kind, drawing 20 tons loaded into three wagons, is given in Table VIII, p. 63.

A compound spring-mounted tractor, such as has been used largely during the past few years by carriers, market-gardeners and others, and is suitable whenever it is desired to carry the load on trailers, is described on p. 58 and illustrated by Figs. 10, Plate 3. The working-cost is given in Table IX, p. 64.

At present there are but few electrically-driven wagons at work in this country, although in a few cases where they have been used unexpected success has been attained. In America, principally owing to the encouragement given by the supply-companies, they are much more common.

So long as electrically-driven vehicles are dependent on the use of accumulators to supply the power, their commercial success is likely to be confined to towns, and to those towns where the distributors of electrical energy are themselves prepared to organize a means whereby not only can existing accumulators be readily charged at a low cost, but standard boxes of accumulators can be provided ready charged, so that the exchange will only cause a few minutes' delay. This, of course, can be carried out only by thorough standardization of the voltage used on electrical vehicles and of the accumulators themselves, and, if possible, of the cases which contain them. As soon as this is done, a great stimulus will be given to the use of the electrical vehicle, which after all is an ideal one, not only for a town carriage, cab, or light van, but for all classes of small distributing-vehicles now used by tradesmen.

It seems best to begin the discussion of this interesting subject from the engineer's standpoint by comparing the road-locomotive with the railway-locomotive.

Power Required to Drive Motor-Vehicles.

The first point of difference is that the short-period power, or effort, which must be exerted to propel a laden road-locomotive varies through a far wider range than in the case of a railway-locomotive.

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This is probably due not only to the more severe gradients that are met with on the road, but also to the difference in rolling-resistance due to the great variation of the surface over which road-vehicles have to travel.

So long as horses were used for draught, it was not generally realized what great power they are able to exert for short periods. Watt's experiments, which led him to adopt 33,000 foot-pounds per minute as the standard unit of power (1 H.P.), gave a very correct idea of the energy that a full-sized horse can exert throughout a working-day; but although this is the average power, it gives little idea of the short-time effort that is daily exerted by horses when dragging a vehicle over a short length of difficult ground, or up a heavy gradient. It is now known that in these cases horses can, for short periods, make temporary efforts eight times greater than their average power, that is to say, they can do work at the rate of up to 250,000 foot-pounds per minute for an appreciable period.

Those who are bicyclists have doubtless appreciated the fact that men also are capable, when riding over heavy ground, or up a short length of hill, of making a temporary effort ten times greater than the average effort they are able to maintain during a day's journey.

The designer of the road-locomotive has to imitate this elasticity in animal effort by providing in his engine sufficient power for the maximum demand, and means of easily changing the ratio of the gear interposed between the crank-shaft and the road-wheels, so that the piston-speed need not vary through the very wide limits which the conditions of the road would demand if the road-vehicle were direct-coupled. By employing this large power-margin and change of gear-ratio, the flexibility of effort shown by the horse or by the bicyclist has been imitated with a certain degree of success.

In order to discuss this power question in a concrete form it may be stated broadly that the maximum output of power demanded from the engine of a motor-car is when that car is mounting the steepest gradient of the road against a head-wind and at a speed as near the legal limit of 20 miles per hour as is possible. In order to calculate this power, the various resistances must be considered, the sum of which must be multiplied by the distance traversed. In the heavier and slower vehicles, the chief of these is the rolling-resistance of the road itself, with which, in the case of horse-drawn vehicles, it has been usual to include the axle-friction.

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Rolling-Resistance: the Road and the Wheel.

The experimental work carried on by General Morin and others in order to determine the resistance of all classes of road-surfaces with different diameters and widths of wheel have not, in the Author's opinion, given data sufficiently accurate to be useful for modern power-calculations. In most cases the instruments employed, not being self-recording, were very difficult to read on account of the rapid oscillations of the indicating needle, due to the irregularities of the road-surface. These oscillations are so violent that it is a matter of extreme difficulty for an observer to take records that are of value unless some steadying resistance is added, *e.g.*, by drawing the vehicle up a known accurately-laid-out gradient and deducting from the results the pull due to gravity. This is probably the reason why the data obtained by the Society of Arts[1] in 1875, in testing the tractive resistance of a London omnibus, differ so widely from those obtained by others, including the Author.

The Author, when in charge of the Government steam-train in India, attempted at various times between the years 1870 and 1875 to obtain the rolling-resistance of the vehicles forming the Government steam-train on portions of the Grand Trunk Road of India. Experiments were made to determine the acceleration of wagons allowed to run down accurately-measured inclines, and in this way some data were obtained which were more concordant, and probably therefore more accurate, than results previously noted.

Within the last few years the British Association has made a grant to a Committee to construct a self-recording dynamometer under the superintendence of Dr. H. S. Hele-Shaw, M. Inst. C.E., to carry a step farther this question of road-resistances; but up to the present not much progress has been made, beyond corroborating in a measure some excellent work carried out by Mr. Michelin in France to determine the reduced resistance due to the use of pneumatic tires.

Mr. W. Worby Beaumont, M. Inst. C.E., in his work "Motor Vehicles and Motors," includes among tables of road-resistances certain tables compiled from the experimental work of Sir H. Parnell and by Mr. H. J. Waters, in the latter case for the Missouri State Agricultural Department. The figures of Mr. Waters appear to be valuable, and they agree fairly closely with the results obtained by the Author.

For present purposes the Author believes that the following figures are sufficiently accurate for power-calculation:—

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[1] Journal of the Society of Arts, vol. xxiii, p. 699.

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	Lbs. per ton.
Rolling- and axle-resistance of vehicles fitted with pneumatic tires on granite, asphalt, and wood pavements, and on average macadam in dry weather, at all speeds up to 40 miles per hour	40
Same in wet weather	50
Rolling- and axle-resistance of vehicles fitted with solid rubber tires at speeds up to 15 miles per hour on asphalt, granite, and wood pavement	50
On good macadam, dry	60
On average macadam, wet	80
Rolling- and axle-resistance of vehicles fitted with rigid iron or steel tires of the ordinary width used for town vehicles such as cabs, omnibuses, and the lighter vans, at speeds up to 10 miles per hour :—	
On granite, wood and asphalt	50
On good dry macadam	65
On average macadam	75
On wet macadam	90

The rolling-resistance of a London omnibus determined by the Society of Arts in 1875 as 17 lbs. per ton on granite pavement and 27 lbs. per ton on asphalt roadway, is probably incorrect.

The lowest rolling-resistance, namely, that obtained by Mr. Michelin during an extended set of trials to determine the reduction in resistance by using the modern pneumatic tire has been accepted by the Author, as it has been checked and corroborated up to speeds of 40 miles per hour by calculations based on the results of the Tourist Trophy Race of 1906, mentioned later on. With such tires, what may be called the "hysteresis" of the tire is so small that the rolling-resistance seems to be practically constant through a wide range of speed. The only conditions under which the rolling-resistance of pneumatic-tired vehicles exceeds 40 lbs. per ton appears to be on roads having a very soft crust.

With the exception of Mr. Waters's tests, very little is known about the rolling-resistance on inferior classes of roads. The Author found that when traction-engines were used during the late South African war to draw trains of broad-wheeled wagons over the hard veldt, the resistance, calculated from the power exerted by certain engines tested, was nearly 85 lbs. per ton. In this case the wheels were of the ordinary traction type, having rigid tires with cross strips.

The maximum rolling-resistance met with is when the wheel rolls over a surface which yields slowly, such as half-dried clay roads which, according to Mr. Waters, may give a rolling-resistance of as much as 315 lbs. per ton, even when broad tires are used, and a much higher result with narrow tires.

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Effect of Climate on Road-Surfaces.

Whereas the designer of a railway-locomotive has to deal with a roadway of regular character, the designer of the road-locomotive is compelled to design the wheels and the vehicle so that the latter can adapt itself to roads over which he has no control, and which, under existing conditions of road-management, differ very widely in the general contour and in the character of the surface itself, varying with the nature of the materials used for road-metal, and in the care with which they are maintained.

Up to the present, the whole of the improvement has been in the vehicle itself. Beginning with the traction-engines, these use various classes of improved rigid wheels and spring-wheels of all kinds. The lighter vehicles have from the first been fitted with wheels having elastic tires, and finally wheels fitted with pneumatic tires in their present perfected form have appeared. All of these, especially the last, have been designed to meet the difficult conditions presented by the faulty roads themselves. Throughout this period of improvement of the wheel and vehicle the road-authorities have done little or nothing to improve the roads, and this fact of itself has made the improvement in the vehicle more costly.

During the 50 years that traction-engines have been in use on the roads there has been continual conflict between their owners and the road-authorities. The owners of the engines have often been heavily fined for damages done to imperfect roads, the damage nearly always consisting in breaking through a road-crust which was inadequately supported by its foundation. The result has been that wheels intended to bear on the largest possible road-surface are very commonly employed. Wheels up to 7 feet 6 inches in diameter and 18 inches wide are used on the larger engines, and in the design and construction of these wheels some degree of finality has been reached.

The present condition of the roads, and the possibilities of their improvement, must be discussed before the question of rolling-resistance is left. Hitherto road-makers have relied on water as the binding medium to enable them to consolidate the road-surface. It has therefore been found necessary to make the surface sufficiently porous to retain the desired quantity of water, and in order to attain this end and to give facility for the surplus water to drain away, roads are at present constructed with a curved cross section or camber, which is frequently carried to great excess.

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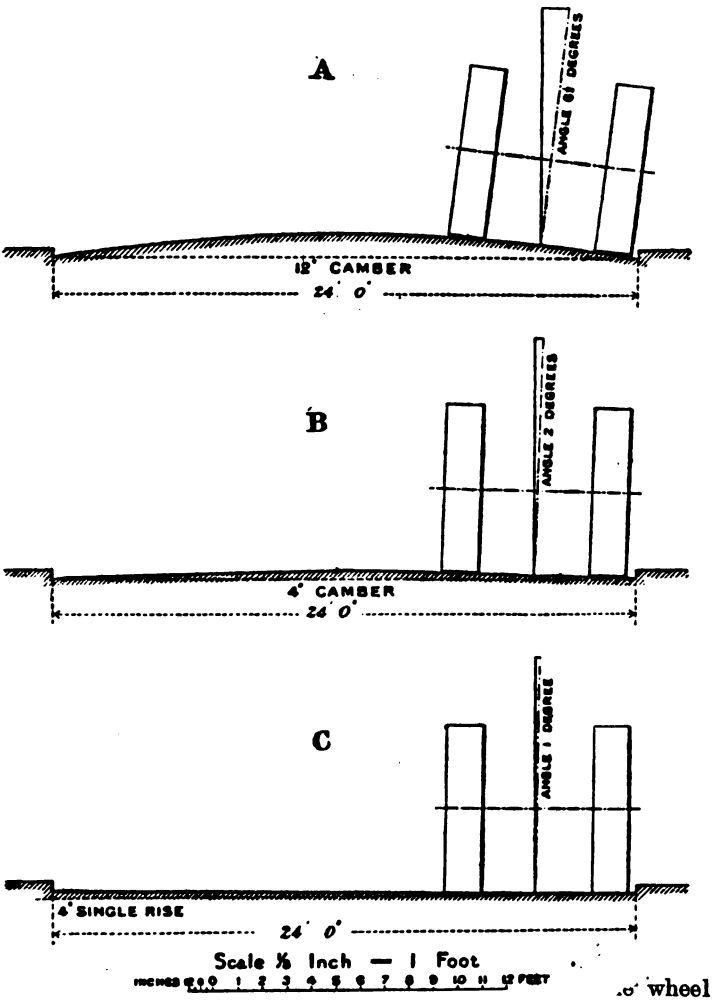
In *Figs. 11*, A shows the effect of such heavily cambered roads on the wheels of vehicles, and especially on the broad wheels of traction-engines or motor-wagons. It shows how impossible it is at present

Figs. 11.



...wheel ...clay roads for a designer to adapt satisfactorily any rigid-tired wheel ...ance of as accommodate itself to the road-surface, and thus ... and a much area of contact as possible. This increase of contact ...

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reducing the wear of the wheel as well as that of the road-surface; the curved surfaces, however, militate against it. There is little doubt that if future roads can be made with waterproof materials, this excessive camber can be reduced so that, instead of the road forming a single curve as in case A (*Figs. 11*), sufficient drainage can be provided for wide roads by making the road, as seen in cross section of two straight slopes meeting at the centre-line (case B), or, in roads 30 feet or less in width, by one slope, the drainage being all to one side (case C). On a road of this cross section wheels would roll with greatly reduced resistance and less wear and tear, both to wheel and to road.

The science of road-construction has advanced but little since the days of McAdam. Since he established the principle that if the road-metal be broken up into angular fragments not exceeding 2 inches in diameter it can be pressed into a monolithic surface, and thus be rendered capable of spreading the weight of the wheel over a greater area of the foundation underlying it, all that was further required was to perfect the system by cheapening the processes of breaking and consolidating the metal; but unfortunately the road-authorities of England have been lulled into false security by the many years of excessively light traffic on their roads during the period when they were used practically only for local traffic; so that they have used faulty materials and faulty methods of construction, the consequences of which the public are now reaping in the disintegration, dust, and rough surface caused by the resumption of traffic. For this the motor-car is really not responsible. If the present amount of road-traffic, which is due to the demand for fresh air and a sight of the country at week-ends, had to take place with horse-drawn vehicles, the nuisance to those resident near the main roads would be almost if not quite as serious as at present; for although the speed would be less, and the dust raised less, a larger number of horses would be used, so that the badly constructed roads would be chipped and broken to an even greater extent than they are at present. This matter has been debated recently and fully in the discussion on the Papers by Messrs. Jebb and Blackwall,[1] and it is therefore unnecessary to labour it further than to point out that the present system of relying on water as a means of holding the top of the road in position cannot longer be tolerated. In the English road-surface water can be relied upon only for very few days in the year and in order to drain surface suffi- water to drain cross section or

[1] "A Plea for Better Country Roads," Minutes of Proceedings p. 1. J E. Blackwall, "Country Roads for Modern

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to bind the finer gritty material, which is of such importance to the top of the road. In most cases either the road is too dry, so that the finer material is loosened, moved, and eventually lifted by the wheels of the passing vehicles and blown away by the wind in the shape of dust; or in wet times these same particles form, with the excess of water, a fluid mixture which acts as a lubricant to the larger pieces of road-metal, allowing them to roll one on another instead of keeping them in their place: for the maintenance of the road in a monolithic condition depends wholly on the larger pieces of road-metal remaining firmly interlocked by the cementing mass of the smaller particles, combined at present with water, but which, in future, must be combined with something which will not readily evaporate. When these small particles are so cemented together that they remain in position partly between and partly on top of the larger pieces of metal, and are not readily removed from this position by the passage of traffic over them, then a road is obtained which presents much less rolling-resistance, causes less noise and no dust, and costs probably less for maintenance.

During the last few years, various methods of binding or toughening the top of the road have been suggested. Mr. E. P. Hooley, M. Inst. C.E., County Surveyor of Nottingham, first suggested impregnating hot blast-furnace slag with distilled tar. The tar, which is so abundantly produced at gasworks, is cheap, and is readily obtainable all over the country; and if, as has been done by several of the more enlightened among the surveyors, it be properly toughened by distillation and by the addition of suitable tempering materials, it acts very efficiently as a binding material under English climatic conditions of temperature and moisture. The tar can now be procured tempered to the stage of being not too soft for the warmest summer day, or too brittle in the frosts of winter. When tar in this condition is used, and the metal of the upper crust of the road to a depth of 4 inches is thoroughly impregnated with it, a new ideal in road-construction can be attained. The road becomes practically waterproof; it can be laid with the single slope above mentioned, so that all the water can be drained off to one side; the wheels which roll on it can bear on the full width of their cylindrical surface; side-slip or skidding can be reduced to a minimum; and there is great hope that the wear of the surface of the road itself—and certainly that of the road and the wheel taken together—will under these improved conditions be so greatly reduced that the cost of maintenance of the two taken together will be much less than heretofore.

It is impossible within the limits of this Paper to go more deeply into this subject, although it is of extreme importance from the

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point of view of decreasing the road-resistance and increasing the durability of the self-propelled road-vehicle. The toughening of the top of the road by tar, even in the modified form of tar-painting or spraying the upper surface, has had an extraordinary effect. The rolling-resistance is reduced, for with a water-bound road the surface is always rough and serrated, although the serrations are minute and, being usually filled with dust, are not easily noticed. These serrations cause a tremor, attended by noise and vibration in the vehicle and by increased rolling-resistance. With a tar-toughened road the serrations disappear, and there is a remarkable absence of the tremor and vibration. This is evidently due to the retention in place of the small particles of gritty material, and, from what has been said, it is difficult now to estimate what effect this will have in reducing the cost of road-maintenance; but even if the road itself does not cost less, and the saving in maintenance is confined to the vehicle, the improvement must take place, and it must be left to the legislature to divide fairly the cost between the road-repairer and the road-user.

As, however, there is little hope of obtaining these improved conditions of road-maintenance within the next few years, it is useful to point out how much might be done even now by road-men by earlier repair of the cavities which form so quickly on macadam roads and are due to the water binding, and in paved roads are due to originally faulty blocks or subsidences in the concrete foundation. In both cases a few shillings spent on filling the cavities, or substituting new blocks, or beating in new metal, would save many pounds of expenditure by the owners of vehicles. The Author has in his mind one hole in the wood pavement near the Royal Albert Hall which was noticeable 18 months ago; it could have been repaired at any time at the cost of 10*s*., and it has damaged vehicles of all kinds, to the extent of possibly several hundred pounds.

The Author feels that he will be expected to mention the question of the undoubted nuisance at present caused to owners of road-side property, and to other users of the highway, by the dust raised by motor-cars. This question has engaged the attention of the Automobile Club during the past 4 years, and some very definite data have already been obtained. It has been ascertained beyond doubt that the dust is partially due to the wheels themselves, which disturb and carry to a certain height from the ground the layer of dust that exists on the road; but this would do little or no harm, and would not be carried to any great distance, if it were not for the strong current of air that is forced underneath the car, and which, as it expands at the rear of the car, seizes upon and carries high into the air, not only the dust moved by the wheels but the dust that has

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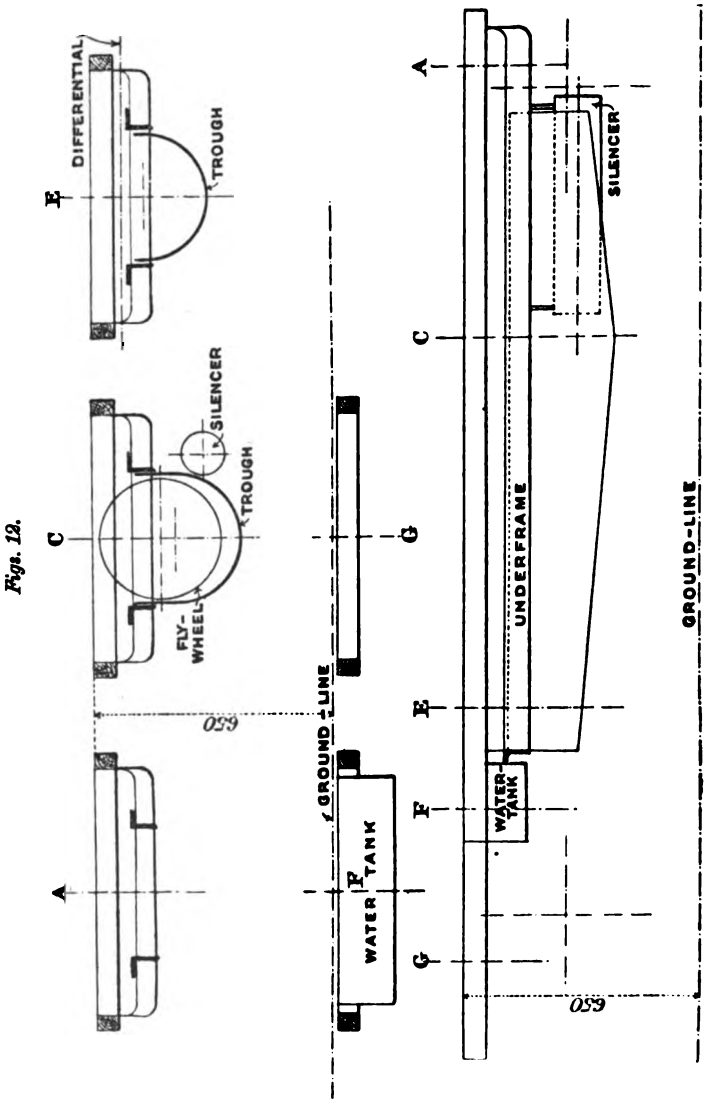
been swept off the space between the wheels by the backward directed air-currents. The Committee appointed to investigate this matter



Figs. 12.

have found that much may be done by modifying the shape of the under-surface of the car. The ideal form for the shape of the under-

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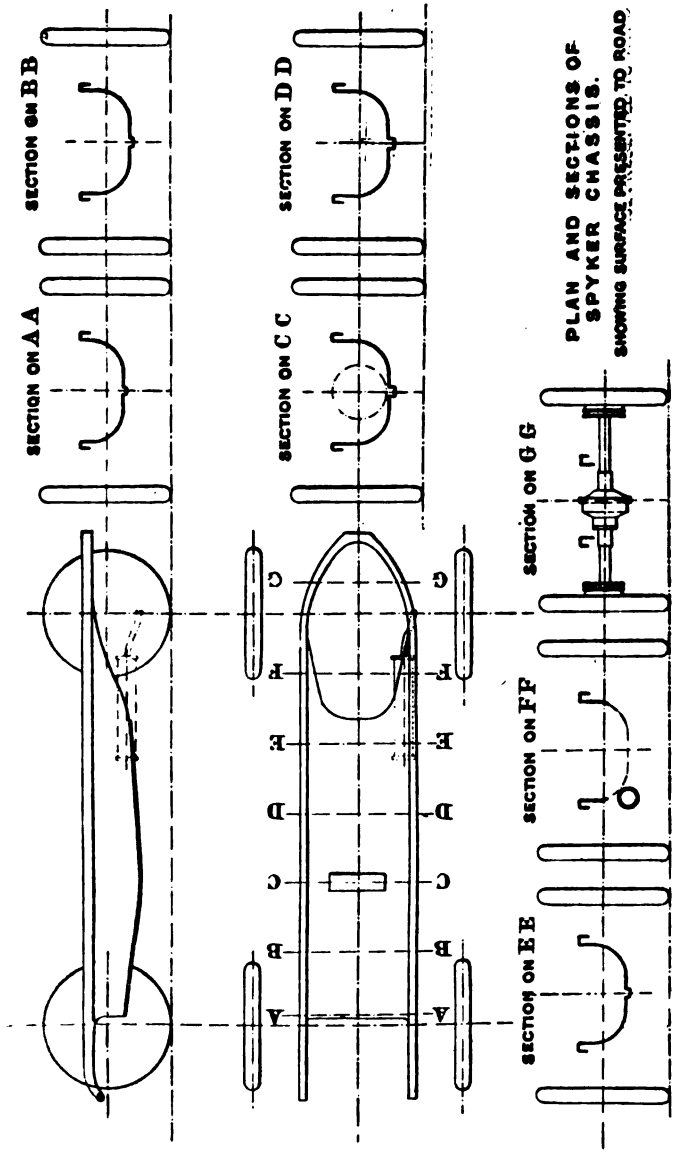
body would be that of the lower half of a fish, with fine lines towards the back of the car.



Figs. 13.

Through the courtesy of the Automobile Club the Author is able to show two diagrams, *Figs. 12* and *13*, which illustrate how this

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can be carried out in practice, and it is only fair to say that cars built with the under-surfaces so modelled have shown remarkable freedom from dust-raising, even when driven at speeds exceeding 30 miles per hour over existing roads.

Up to the present, in spite of the efforts of the Automobile Club, manufacturers of cars have not paid nearly enough attention to this important matter. The Author believes that, if these general lines of construction were followed in all cases, then, without any further modifications of present road-construction, a considerable share of the present odium attached to cars on account of their dust-raising would be removed; and that, with the improved road-construction which has been advocated in this Paper, aided by improved construction of cars, the dust-nuisance would disappear entirely.

Air-Resistance.

The other resistance, which in faster vehicles is of considerable importance, is the air-resistance, which increases as the square of the velocity at which the vehicle moves. It is therefore of considerable importance in vehicles running at speeds exceeding 15 miles per hour, but may be neglected in the case of the heavier vehicles moving at lower speeds. Dr. Stanton's experiments at the National Physical Laboratory have shown that the square-of-the-velocity law is correct within the limits under consideration, and that calculation of the air-resistance may be based on the figure of 0·27 lb. per square foot of surface exposed at a speed of 10 miles per hour or 880 feet per minute.

Road-Gradients.

If these figures be applied to a motor-car of a kind very commonly met with—that is to say, one provided with engines which give 20 B.HP. at the crank-shaft, or after making ample deductions for gearing-losses 16 B.HP. at the periphery of the driving-wheels, and which has a windage-area of 25 square feet—and if the figure of 40 lbs. per ton, given for road-resistance with pneumatic tires, be adopted, it will be found that at a speed of 38 miles per hour the total road-resistance will be 52 lbs., and the air-resistance will be just under 100 lbs., making the total resistance 152 lbs.; so that the net 16 HP. provided will be sufficient to drive such a car on a good level road in still air at 38 miles per hour. When

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the same car is driven up a gradient of 1 in 14 at the rate of 19 miles per hour, or exactly half the first-named speed, there is the added resistance due to gravity to be overcome, but a considerably reduced wind-resistance; in this case the total is 300 lbs. or nearly double that in the first case; so that, the speed being one-half, the power will be the same, it being noted that in order that the engine may exert constant power throughout, the gearing-ratio must be altered from one in the first case to two in the second.

Thus, if the owner of this car be law-abiding, and drives his car consistently throughout within the legal limit—say at 19 miles per hour—he will, when hill-climbing on 1 in 14 or upwards, exert the full power of his car, whereas on inclines of less severity he will exert less power; and on the level, if he only runs at 19 miles per hour, he will drive the car at only one-third of its power, and then the engine, if an internal-combustion engine, will be worked at comparatively low efficiency.

This necessity for providing excess of power in petrol-driven cars has resulted in a general increase of cylinder-capacity, but owners rarely know how dearly they pay for the rapid hill-climbing power that they thus obtain; for not only are their cars larger and more expensive to buy, but the weight is so much increased that the cost of fuel and tire-maintenance is also largely enhanced.

When motor-cars are driven at racing speeds, or are driven at moderate speeds against a head-wind, the power absorbed by air-resistance may be very large, as in this case the velocity of the wind has to be added to that of the car, and the resistance varies as the square of the total velocity thus obtained.

From data which have been furnished by the Technical Committee of the Automobile Club, of the weight, speed, cylinder-capacity, and petrol-consumption of the cars which recently competed in the Tourist Trophy Race in the Isle of Man, the Author has been able to prepare the following figures, which show the total road- and axle-resistance, the air-resistance, the net horse-power-hours and the petrol-consumption per net horse-power-hour for the two most interesting cars, namely the winning car and that which used the smallest quantity of petrol. It will be seen that the total efficiencies of the engines and of the transmission-gear in both cars are practically identical and are exceedingly high; and the designers are to be complimented on the excellence of these figures. They prove conclusively that for pneumatic tires a road- and axle-resistance of about 40 lbs. per ton ($W \times 0{\cdot}018$) is approximately correct for all speeds, and they confirm Dr. Stanton's experimental work previously mentioned.

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	Winning Car.	Car which used Least Petrol.
Average weight, *i.e.*, gross weight deducting half petrol used . . . . . Lbs.	2,743·5	2,627·75
Total road- and axle- resistance, *i.e.*, W × 0·018. Lbs.	49·3	47·4
Area exposed to air-resistance, including 1·2 square foot for exposed head and shoulders of driver. Sq. ft.	18·31	16·1
Air-resistance per square foot at the average speed attained . . . . . Lbs.	4·16	3·65
Total air-resistance . . . . . Lbs.	76·8	59·0
Average speed . . . . . Miles per hour	39·29	36·8
Average speed . . . . . Feet per minute	3,470·0	3,250·0
Total of road-, axle- and wind-resistance . . Lbs.	126·1	106·4
Total average net horse-power . . . . . HP.	13·35	10·5
Total net horse-power-hours, *i.e.*, average horse-power by time occupied . . . . . HP.-hrs.	53·8	46·6
Total petrol used . . . . . Lbs.	44·9	38·5
Petrol used per net horse-power-hour . . . Lbs.	0·83	0·825

Wheel-Construction.

It has been pointed out before that the 50 years' development of traction-engines has given a very satisfactory traction-engine wheel. The wheels for traction-engines and for many of the motor-wagons have followed what is now well known as the stereotyped traction-engine practice, that is to say, cast-iron or steel hubs into which flat-bar spokes are fixed by being cast in place, these spokes being arranged in two rows so that the spokes starting from the outer end of the hub are riveted to the rim on an inner flange, whereas conversely those from the inner end of the hub pass to the outer flange of the rim. The rims consist of one or more tee-bars according to the width required. These bars are bent, welded into a ring, and turned on their periphery, and the spokes are riveted to them. Finally, strips are riveted across them diagonally, with small spaces between the strips, according to conditions carefully laid down by the Local Government Board.

This form of wheel has been used by traction-engine builders for the last 40 years and has survived. It has shown that it is capable of withstanding extraordinarily severe work. Its defects are that after long runs over hard roads, there is a tendency for the rivets which connect the outer ends of the spokes to the tee-bars to work loose, and it is necessary to rimer out the holes and close in larger

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rivets, or in some cases to replace the tee-bars; but where such engines are used on soft ground the life of the wheels is very long, in some cases extending to 15 years. The Author used these wheels for transporting heavy guns in South Africa with the greatest success. This was the only kind of wheel which suited the very heavy weight of the 6-inch quick-firing naval gun used on shore for the first time, which, with its carriage, weighed 12 tons.

Designers of the early motor-wagons which took part in the Liverpool competitions evidently had not taken much notice of traction-engine practice, and they began with driving-wheels only 3 feet in diameter, with disastrous results. They were led to this error by the great apparent advantages and convenience of keeping the driving-wheels below the level of the overhanging platform of the wagons, so that in most cases the sides could be let down to conceal the wheels entirely—in this respect copying railway practice; and the designers of motor-wagons have kept this matter of convenience so strongly before them that in few cases have motor-wagons been put on the road with wheels of sufficient diameter to get the best results, apart from this one convenience of loading from the side.

There are many kinds of wagon wherein this loading question does not arise, and on these wheels of much larger diameter could be provided and housed in properly shaped casings.

There is little doubt that much of the heavy wear and tear and vibration caused by the motor-wagon of to-day is due to the small diameter of the driving-wheels, for these wheels as they go in and out of the concavities in the wood pavement not only cause disastrous shocks to themselves, but actually communicate vibration to surrounding houses. The severity of this shock would diminish almost inversely as the square of the diameter of the wheels.

The adoption of these small diameters has left very little scope for design in producing lighter wheels of sufficient rigidity and strength to resist transverse shocks. The small tractors which may be seen taking heavy loads of vegetables and fruit into Covent Garden Market, and which are very light for their size, weighing in some cases only $3\frac{1}{2}$ tons, have wheels never less than 4 feet in diameter, and in tractors of 5 tons weight the diameter has been increased to 5 feet, with excellent results in diminishing vibration, noise, and wear and tear of the wheels themselves, as well as of the engine they carry.

In the earlier motor-cars, suspended or wire wheels, copied from bicycle patterns, were largely used; but since the diameter of the wheels has been decreased owing to the introduction of pneumatic

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tires, wheels having wooden spokes and felloes of what is known as the artillery type have largely taken the place of these wire wheels. The artillery wheel has been greatly improved, and some of the American examples, in which hickory is used for the spokes, are beautiful specimens of wheel-construction. From the engineer's standpoint the wire wheel has been abandoned for insufficient reasons, although some of the best constructors, such as Lanchesters, have continued throughout to use them with extremely satisfactory results; for if they are properly designed, and the details are sufficiently considered, their construction can readily be standardized, and they are far more rapidly repaired, either on the road or where skilled labour is difficult to obtain. Moreover, wire wheels are certainly much more elastic than the artillery pattern, and thus reduce shocks which can be only partly absorbed by rubber or pneumatic tires.

A few makers of motor-omnibuses and motor-wagons are using with satisfactory results steel wheels, the spokes, hub, and rim being cast in one piece. Others are using wooden disk wheels, the whole of the space between hub and felloe being filled with arch-shaped pieces on to which the ordinary rigid tires are compressed hydraulically. Quite recently, wooden wheels have been constructed with the spokes arranged tangentially; these, called tangent-wheels, are said to give good results and are more elastic than wooden wheels with radial spokes.

Elastic Tires.

Wheels intended to run on any road-surface at speeds exceeding 8 miles per hour must have soft tires, otherwise the noise due to the crunching of the small particles of road-metal and the metallic clang of the rigid wheels becomes so annoying and deafening as to be of itself prohibitive. Modern motor goods-vans, omnibuses, and all passenger-vehicles intended to run at speeds above 8 miles per hour must necessarily have soft tires. First in order of these is the solid rubber tire introduced, about 1868, by the late Mr. R. W. Thomson, of Edinburgh, who had 20 years previously invented the pneumatic tire almost precisely in the form in which it is now seen.

Solid rubber tires occupy a position midway between rigid and pneumatic tires. It is very difficult to design them so as to obtain reasonable durability of the rubber covering, but as they are free from the uncertainty and delays which follow the puncturing of the pneumatic tire, they are largely used, and their use is likely to continue. The difficulties in working these tires on ordinary roads

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are not generally understood. They occur chiefly on account of the fact that rubber is not an elastic material. It is true that it is able to change its form and cross section when compressed between the rim of the wheel and the road; but it cannot be reduced in volume. Therefore, when rubber in the form of a solid tire is interposed between the rim and the road, there is always a tendency for it to be rolled forward, as a cook rolls pastry, and this forward rolling action, which is aided by the tendency to tangential slip of the driving-wheel, renders it extremely difficult to secure a solid tire in position; consequently, such tires are always tending to tear themselves away from the rims. The only palliatives that have hitherto been found are to make them take the form of tubes having very thick walls (which when used for bicycles were called "cushion" tires), or to produce nearly the same effect by dividing them into two or more bands of narrower section, placed side by side with spaces between.

One of the main causes of the rapid development of the modern motor-car has been the fact that it was able to avail itself of the pneumatic tire which had been developed for bicycles. When discussing the progress made by modern motor-vehicle designers, it is far too much the fashion to take it for granted that the tire is an inevitable nuisance, one of the weak points in the car; and as a rule anything but praise is heard of the tires, whereas really the pneumatic tire has contributed more than anything else to the popularity and comfort of the car. Moreover, although far from perfect, and a cause of great annoyance—very largely on account of the faulty construction of the roads—the pneumatic tire already shows in its construction features of extraordinary excellence which reflect the greatest credit on those who have quietly and patiently developed it, almost, it may be said, in the face of popular abuse.

The present pneumatic tire is a wonderful piece of mechanism, which behaves in a very satisfactory manner when the extraordinary strains to which it is subjected are considered. Anyone who takes notice of a car standing or moving on one side of a heavily cambered road will see how perfectly the pneumatic tires adapt themselves to very difficult conditions. Although the car is on a slope of varying curvature, the inclination of the rigid rims being of course parallel to the inclination of the axle, the cross section of the tire maintains its original form of contact with the rim of the wheel, but on the side next the road splays itself out in an irregular manner to fit the surface. At this point the strains in the textile material, on which the cover depends for its strength, are very severe, so that all that has been said as to the advantages

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of reforming road-construction, particularly in the direction of removing excessive curvature of the surface, will have the effect of greatly prolonging the life, and consequently reducing the cost of maintenance, of tires of this class.

Before leaving wheels and tires something must be said on the subject of spring-wheels. It will be seen that pneumatic tires introduce a perfect and continuous elastic cushion at the point where it is most efficient, namely between the rigid rim of the wheel and the road. The farther the elastic cushion or springs of the car are removed from this position, the less efficient they become, as all unsprung portions, *i.e.*, those interposed between the cushioning-devices and the roadway, have the effect of either damaging themselves by the continual vibration and blows they receive, or of damaging the roadway itself. Long before pneumatic tires were brought to their present state of perfection, an army of inventors had attempted to substitute for the solid rubber tires a cushion, placed as near the periphery of the wheel as possible, in the form of springs interposed at some point between it and the hub.

At the time of writing this Paper, several of these devices are under test and some progress has been made, but up to the present no perfectly satisfactory spring-wheel has been put on the road. Some of the reasons for the failures are easy to explain, some of them are rather obscure.

When the spring-wheels are driving-wheels it is found necessary, in addition to introducing springs, to allow of radial springing action, to transmit the tangential driving-strains by sliding-devices or by some system of tangential linkage, the latter being the best; but in all cases, on account of the considerable rubbing motion at this point, which occurs close to the road-surface, where the rubbing surfaces are exposed to grit, dust, and mud, their durability is very small, and all attempts to shield them from the mud have hitherto only resulted in the introduction of fresh sliding surfaces. The best results have been obtained when the two actions of radial springing and tangential driving have been combined in one set of tangential springs, the access of mud and dust to the wearing parts being prevented by leather covers; but of course the leather has a limited life.

It is with no desire to discourage the numerous spring-wheel inventors that the Author points out the serious difficulties which lie before them. These difficulties are greatly enhanced by the excessive road-camber before alluded to, which causes cross strains and extra grinding friction and cutting of the sliding parts; for it is difficult for the sliding surfaces to move in and out towards the centre of the

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wheel when the wheel is running with the weights carried on one or other of the edges of the rim, or when it is subjected to the shock of suddenly descending into and climbing out of the concavities in the road. Convex obstacles are not so objectionable, because when a rigid wheel or a spring-wheel rolls over a convex obstacle on the road, the vehicle is retarded as it mounts the obstacle, and in this way the shock from the descending blow is somewhat reduced; but when the wheel rolls down into a cavity, the converse is the case; it meets the abutment at the farther side of the cavity at the moment of maximum acceleration.

The noise and vibration caused by the motor-omnibus, which in many cases is justly complained of, is very largely due to these shocks to wheels of too small diameter and to the parts connected with them, at the repeated bouncing into and out of these concavities, which exist far too frequently in all wood-paved streets.

Gearing.

It is well known that one of the most important features of the road-locomotive is that the power cannot be transmitted direct from the piston to the road-wheels as in railway-locomotive practice, but that gear of a more or less complicated description must be interposed; and moreover, in the case of the internal-combustion engine, means must be provided to change the ratio of this gear. When steam is used, this change of ratio is not necessary for small vehicles, but for motor-wagons and tractors, on account of the extreme variations of road and load, one or two changes of ratio are generally provided.

The simplest form which gearing can take is that used by Hancock, the crank-shaft driving the axle by a chain, and this, the simplest, is also the most efficient form. If the efficiency of the railway-locomotive's direct drive be taken as 100, it is possible to obtain from single reduction by chain as much as 96 per cent. of this. *Figs. 14* show seven methods of transmitting the power from the piston to the road-wheel, beginning with the 100 per cent. efficiency of the locomotive drive. In each case the Author has calculated the cylinder-capacity required to furnish the same amount of power at the driving-wheel, and has shown it graphically to the right in the form of an area varying between 510 cubic inches of cylinder-capacity in the case of the direct drive up to 640 cubic inches of capacity for the case of the two side-chain double-reduction drive (*e*). In *Figs. 14*, (*a*) shows the direct or locomotive drive. A single-chain

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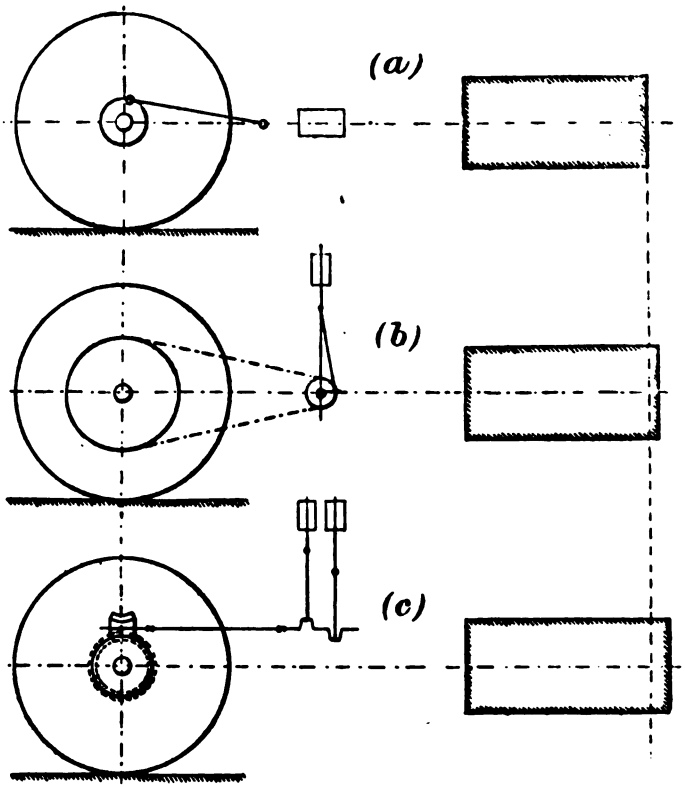
Figs. 14.



Diag. *Figs. 14.*	System.	Cylinders.			Efficiency of Transmission.	Gear Ratio.	Cylinder Volume per Revolution of Driving-Wheel.
		Number.	Diameter.	Stroke.			
			Inches.	Inches.	Per Cent.		Cub. Ins.
a	Direct drive . . .	2	4·5	8	100	..	510
b	Single-chain drive .	2	2·9	5	96	4 to 1	532
c	Worm drive . . .	2	3·0	5	92	4 „ 1	556
d	Bevel drive . . .	4	3·0	5	88	4 „ 1	580
e	Bevel and chain drive	4	4·5	5	80	4 „ 1	640
f	Spur-wheel and chain drive	4	4·3	5	86	4 „ 1	596
g	Spur-wheel and chain drive	4	4·4	5	84	4 „ 1	608

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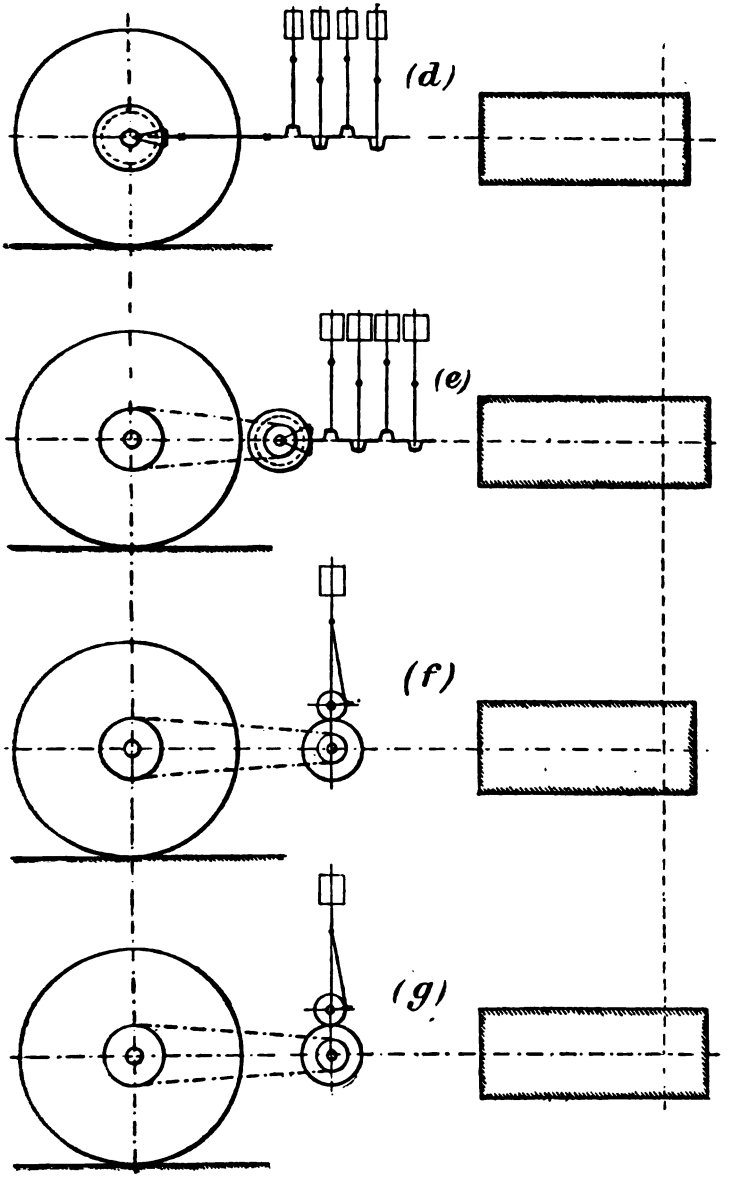
Figs. 14—continued.



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drive is shown in (*b*), and the next most efficient drive of which the Author has knowledge is the roller worm-gear shown in (*c*). In this case the efficiency is 92 per cent. of that of case (*a*). Next there is the bevel-gear drive of the ordinary motor-car (*d*), which at present is probably more largely used than any other. Its efficiency is fairly high, reaching possibly 88 per cent. in the best cases when quite new; and it must be noted that the maintenance of this efficiency depends very much on the means of taking up end thrust in the propeller-shaft, for any end play in the shaft carrying the bevel-pinion causes heavy losses at the bevel-drive. Cases (*e*) and (*f*) are two methods of double reduction. The former is the very common one where two side chains are used, and in the latter there is a single chain placed at the centre, or nearly in the centre, the gearing being straight gearing throughout. In this case, although there is double reduction, the efficiency may be as high as 86 per cent. Finally, (*g*) shows a straight-gear double-reduction drive with two side chains, with an efficiency of 84 per cent. There is thus a range of methods of gearing varying in efficiency between 96 per cent. and 80 per cent. of that of the direct locomotive drive.

It must be noted, however, that these efficiencies are the best possible efficiencies in each case, and can only be obtained, in the case of the petrol-driven engines, when the engines are in the highest gear. When the third gearing-shaft is in motion the efficiencies must be corrected down to the double-reduction scale.

In considering the merits of various forms of gear, and notably in comparing chain-drives with the use of the live axle necessitated by the single reduction in cases *b*, *c* and *d*, it must not be forgotten that such live-axle drives have the disadvantage of increasing the unsprung weight carried by the tires of the back wheels, and this is of such importance that it is found extremely difficult to maintain the tires, wheels, and axles of these cars when rigid or solid rubber tires are used. It is for this reason that double reduction with side chains, which admits of a much lighter back axle, has such stanch advocates among certain designers of cars, motor-wagons, and motor-omnibuses; for, in weighing the advantages of the various forms of gearing, their merits have to be considered, not only in reducing power-losses, but also in facilitating spring-play, and thus the questions of tires, wheel-and-axle construction, spring-play, and gearing are so closely connected that none of them can be modified without considerably affecting the others. Moreover, the roads on which a vehicle is intended to run have an important influence in the choice of

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systems of gearing; for instance, the live-axle drive either by bevel-gear or by worm-wheel probably presents the balance of advantages when used on roads with smooth undulating surfaces free from holes or irregularities which will be affected by the extra weight of the unsprung parts inseparable from this system; whereas the side-chain drive, on account of the reduced weight of these parts, has many advantages for very rough roads or for town roads kept in bad condition.

Constructors of all motor-vehicles, from traction-engines down to the lightest cars, have made extraordinary progress in the improvement of their gearing. All the gear-wheels are nowadays carefully machine-cut out of the solid, and are case-hardened. The use of the propeller-shaft has become possible only by reason of the high efficiency now obtainable from machine-cut bevel- and worm-gear, and by the end thrust of the shaft being taken up by ball-bearings, which enable the end motion of the bevel-pinion to be controlled within extremely narrow limits which were quite unobtainable with the older type of bearing.

The extremely high efficiency claimed for the roller worm shown in case *c* is obtained by using an accurately formed case-hardened worm, gearing into a worm-wheel formed of shaped rollers revolving on radial projections and combined with end-thrust ball-bearings. In this case experimental tests have shown the highest efficiency ever obtained in right-angled transmission.

Steering-Mechanism.

Modern road-vehicles owe a great deal to the Ackermann steering. The ordinary steering-lock and turn-table used by earlier vehicles and traction-engines are not suitable for high speeds, and introduce great difficulties in design; for a space—with which everyone is familiar in horse-drawn vehicles—must be allowed for the front wheels to pass partly under the body, or else these front wheels must be greatly reduced in diameter, which increases the shock-difficulties before mentioned. With the Ackermann steering, however, wheels of fair size can be used.

In the application of Ackermann steering to heavy vehicles it is of considerable importance that the vertical axis on which the steering-wheels are pivoted should fall vertically within the centre-line of the wheel itself, as this greatly reduces the labour of steering.

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Brake-Mechanism.

The brakes used for controlling the speed of mechanically-driven vehicles have been recently the subject of much discussion. In most of the lighter vehicles the driver usually controls his speed by a foot-brake applied to the propeller-shaft or to the countershaft, his emergency-brake being applied to drums fixed direct to the driving-wheels. In most cases the brakes now used work metal to metal, that is to say, metal shoes or pads are pressed either internally or externally against metal drums; but the Author has found that from several points of view better results can be obtained by covering the drums themselves, or by lining the brake-straps, with the fibrous beltings which are used by engineers for driving machinery. One of these, which is known in the trade as "camel-hair belting" but probably contains no camel-hair, works exceedingly smoothly and sweetly. It checks the vehicle with no jar or shock, and does not lose its good properties when it is heated; while the combined wear of the lined strap and of the brake-drum are probably less than in the case of the metal-to-metal systems.

Skidding.

In connection with the brakes it is necessary to mention the important question of side-slip or skidding, the cause of so many accidents with motor-vehicles. Although on very greasy surfaces such skidding occurs with horse-drawn vehicles, its results are not so marked, as the horses themselves, owing to the foothold afforded by their shoes, are able to check the vehicle to some extent; but with the motor-vehicle, when the streets, as is so often the case, are covered with mud which has been churned or tempered until it becomes a true lubricant of a stiff nature, the weight on the rubber tires is insufficient to bring them into direct contact with the roadway; they float on the surface of the mud, and the driver is then no longer able to steer the vehicle. Skidding usually begins on sudden application of the brake, and the vehicle may move sideways or sometimes swing right round, colliding with either the curb or with other vehicles, with disastrous results.

Most of the palliatives used or proposed are intended to enable the wheels to get hold of the actual road-surface, instead of floating on the lubricating mud. They all act by interposing between the wheel and the road-surface projections of reduced area which pass through the mud and allow of interlocking to some extent; but it is

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worthy of note how much depends on the skill of the driver, who acquires by experience the art of checking skidding in its initial stage by almost imperceptible motions of the steering-mechanism, before the sideways movement has reached the point of being uncontrollable.

Chiefly owing to this improvement in the skill of the drivers of motor-omnibuses, the accidents due to the side slipping of these vehicles are not increasing in anything like the ratio of the number of vehicles in use.

Various Constructional Details.

There is no necessity in this Paper to discuss at any length the component parts of the motor-vehicles in use. Many of the burning questions which occupy the technical journals of the day are due to attempts to overcome the difficulties of using the Otto-cycle engine, which gives only one useful impulse per cylinder for two revolutions of the crank-shaft. The use of the Otto cycle is responsible for the multiplication of cylinders up to six and eight, and for the complexity in gear-changing apparatus. No great simplification of the car in the future can be hoped for until something resembling the engine brought out by Brayton, which attained very fair success, has been obtained. Brayton attempted to obtain the simplicity of the steam-engine by providing a means of storing under pressure an explosive mixture in a separate chamber, whence it was passed to the cylinders, and was burnt in a rapid succession of explosions, giving a very square and full diagram. In this way the cylinder-pressure is maintained up to a late period in the stroke, and the engine becomes very suitable for driving road-vehicles.

Various proposals to develop this idea have been brought forward from time to time, some of which have been shown to the Author under the seal of secrecy. As yet nothing practicable has been put on the market, but it is fairly certain that it is in this direction that real improvement must be looked for.

The multiplication of cylinders to obtain regularity of turning moment involves great complexity, from the increased number of valves, joints for ignition, joints for cooling-circulation, and so on. It is an exceedingly difficult matter at present to trace a stoppage due to an ignition-defect in a four-cylinder engine, but the difficulty of locating the trouble in a larger number of cylinders increases in a higher ratio than their number.

Up to 4 years ago, the valves by which the mixture was admitted to the cylinder were operated automatically, that is to say, they

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lifted under the suction of the out-going piston, the charge being drawn in automatically. In the majority of cases these automatic valves have been replaced by mechanically-operated valves, a finger worked from a cam-shaft giving a positive motion to the valve exactly at the correct moment; and the almost universal use of this method shows that it must possess decided advantages.

Volumes might be written on ignition-devices. To the "motor maniac" the subject is no doubt an enticing one. The general tendency has been towards the use of magneto-ignition, which generally works well, but is not easily understood or set right by a driver who has no electrical knowledge.

The water-cooling arrangements of the internal-combustion engine are as a rule positive in their nature. The water is circulated through a radiator by a pump, and much thought has been given to the design of the radiators and circulating arrangements to increase the cooling-efficiency without increase of weight. Mr. Lanchester for several years was faithful to air-cooling, and the possibilities of this question are not finally settled, the Americans having recently attacked the problem a second time with some prospects of success. It is obvious that air-cooling has the advantage of great simplicity, and even now it can be used satisfactorily for small powers.

Superheated Steam.—The great advance that has been made by steam-cars and omnibuses during the last few years has undoubtedly been due to the impulse given by the introduction of the flash-boiler. Five years ago the fuel-consumption, when petrol was burned in a steam-driven car, was three times that of a petrol-driven car; but since the days of the flash-boiler and superheated steam the consumption of the steam-driven car is probably not more than 15 per cent. in excess of that of the petrol-driven; and as the steam-car uses a lower grade of fuel which costs less, the probable cost of fuel for the two cars of equal size and weight is practically the same.

A wide difference of opinion apparently exists between constructors of steam-driven cars as to the comparative advantages of single- and double-acting cylinders. Double-acting cylinders necessitate stuffing-boxes and gland-packing, and to the amateur driver this is a serious matter. By the use of a single-acting engine Mr. Serpollet entirely overcame this trouble, so that the Serpollet engine could be run almost until it dropped to pieces, but without any loss of efficiency, and without giving any trouble on the road; recently, however, Mr. Serpollet has assimilated his practice to that of others, and has adopted the double-acting engine, the results of which remain to be seen.

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White in America is the only designer who has combined compound engines with flash-boilers, and the results of a test made by an independent authority, Professor Benjamin, on an ordinary White car-engine showed an unprecedented result for a steam-engine of this size. The results are given here, and are well worth study by all who are interested in what highly superheated steam can do.

RESULTS OF A TEST ON THE ENGINE AND BOILER OF A 10-HP. "WHITE" STEAM-CAR (OCTOBER, 1904).

Boiler-pressure	263 lbs. per sq. in.
Temperature of fuel	510° F.
Temperature of steam. Boiler	763° F.
" " " Engine	695° F.
Superheat at boiler	353° F.
" " engine	285° F.
Temperature at exhaust	288° F.
Weight of gasolene	6·6 lbs.
" " water evaporated	72 lbs.
Water evaporated from and at 212° F., per pound of gasolene	16·6 lbs.
Evaporation per square foot per hour	5·96 lbs.
Actual water per B.HP.-hour	12·6 lbs.
Gasolene per B.HP.-hour	1·16 lb.
Equivalent steam per B.HP.-hour at 212°	16·3 lbs.
Brake horse-power	11·4
Cut-off	0·75
$\frac{\text{B.HP.}}{\text{Indicated}}$	0·85
Water per I.HP.-hour	10·7 lbs.
Gasolene per I.HP.-hour	0·975 lb.

From these figures it will be seen that the ratio of the calculated actual evaporation to that corrected from and at 212° is 966 : 1,470.

When a flash-boiler is used, the organs of extreme importance are the feed-pumps, which supply the feed stroke by stroke, as it is required by the engine. With the modern steam-car, the speed and efficiency are largely determined by the condition of the feed-pump, varying from high efficiency to a point at which the driver is compelled to overhaul the pump-packing and valves.

Mr. Serpollet has paid much attention to improvements in feed-arrangements. He has entirely separated them from the engine, and has designed an extremely neat donkey-pump which is almost automatic in its action and practically drives the engine. He alone has ventured to adopt the principle of a proportionate feed of oil and water. After having ascertained the rate at which the water can be evaporated by the oil, he feeds the latter to the burner

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and the water to the boiler in these precise proportions. If the duplex pump is slowed down, the fuel and water are reduced in equal proportion, and the arrangement works satisfactorily and is very "fool-proof."

The Fuel Question.

The fuel used by cars, omnibuses, and motor-wagons has been up to the present petroleum-spirit, commonly called "petrol."

This fuel has several great advantages: it is vaporized at a low temperature; it is of a cleansing nature; in an internal-combustion engine driven with reasonable care, little or no deposit is found in the cylinders and passages; and it only causes offensive smell when improperly exploded. Against these merits must be set two or three great disadvantages, the first of which is price. The petroleum-spirit forms a very small fraction of the content of the petroleum-supply of the world. American wells, the petroleum from which yields the largest percentage of spirit, are largely in the hands of the Oil Trust, and there are already signs that the demand is exceeding the supply to a sufficient extent to enable the supply of petroleum-spirit to be readily manipulated by a ring. This scarcity of the fuel which modern petrol-driven vehicles are at present solely designed to consume is one of their greatest defects. There is no doubt that the supply of spirit can be somewhat increased by improvement of carburettors to take the benzines, benzolenes and other spirits of higher specific gravity than the petrol generally used. Hitherto, these benzines have been largely used as the fuel for steam-cars, but they can be used with the internal-combustion engine with but slight modification of the carburettors.

It is with the kerosenes and paraffins, which can no longer be considered spirits, and which have a distinctly greasy feel to the hand, that the difficulties begin. In the first place such fuels are dirty to manipulate. Any that may be spilt, instead of immediately evaporating, as is the case with petrol, creeps all over the surfaces, and there is a pervading smell of paraffin which certainly is a great disadvantage, at any rate, in a passenger-vehicle. Of course this difficulty may be obviated by special precautions, but users of petrol in its present form urge that, until the price of petrol rises far beyond what it is at present, the balance of advantage for private cars will still remain with it.

The kerosenes or paraffins which come from Pennsylvania and from Russia and Borneo, and which are also distilled in Scotland from some of the shales, can be worked satisfactorily in most forms of stationary oil-engines; but hitherto they have not been satisfactorily

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worked in motor-cars where the action is intermittent, and the difficulty of preventing smoking, clogging, and smell is thereby greatly increased.

The one engine that burns all kinds of the heavier oils equally satisfactorily is the Diesel engine, in which a small charge of the liquid oil is introduced into the direct presence of a stream of air heated to a very high temperature, which sprays it and carries it to the explosion-chamber practically in an atomized form. It is in this direction that the extended use of paraffin and the heavier oils in the internal-combustion engine must be hoped for.

In the matter of raising steam for steam-engines, whether with flash-boilers or with the older form, difficulties of the same order are encountered. Whereas, with the benzines, the burners and vaporizers will work for months without clogging or requiring special attention, when paraffin is used the same burners require blowing out every few hours, otherwise tarry matters accumulate, and the orifices through which the gaseous products escape become choked.

The simplest and more efficient method of using the paraffins and the heavier oils is that adopted on board ship for steam-raising, namely, atomizing the oil by a jet of superheated steam or heated air, the latter being theoretically the more efficient of the two; but the Author is not aware of any case where the arrangements adopted have been successful for road-purposes, although this is so much desired.

In this connection it may be remarked that the world's supply of the heavier oils which remain after the spirits and paraffins have been distilled from them is very large, and as they must be got rid of, it is very improbable that their supply can be sufficiently controlled to make the prices unreasonable.

With the more difficult oil-fuels it is of the greatest importance that the combustion should be perfect. Unfortunately, the point of highest efficiency is that at which the air-supply is cut down to the lowest possible limit, that is to say, just to the smoking- or smelling-point. When excess of air is used, the efficiency is sacrificed at the expense of smokelessness and freedom from smell.

Cost of Working Motor-Vehicles.

It has not been at all an easy matter to obtain figures which will be of value to engineers on this, the commercial and most important side of this new development of engineering. The conditions under which road-vehicles are worked vary through such

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wide limits that very conflicting estimates are put forward: those by manufacturers are, as a rule, far too favourable, while, on the other hand, users who have been at work for some time do not willingly publish their results, in some cases owing to their being ashamed of the poor results obtained, in other cases for obvious trade reasons; but the Author, as one of the officials of the Motor-Van, Wagon and Omnibus Users' Association, has fortunately been able to secure the figures given in Part II (Tables I–IX, pp. 59–64) of this Paper, which give a very reasonable idea of the present state of the cost of mechanical haulage.

With regard to Tables IV, IVA, and IVB, which relate to the cost, brought up to date, of working motor-omnibuses in London and in the country, it is necessary to explain the system of working which has been generally adopted. In London, two shifts of men are employed, one relieving the other in the middle of the day, and by this means the average mileage shown in Table IV has been obtained. In the country, however, only one shift of men is employed, and the mileage is considerably less.

In further explanation of Table IV, the days on which the omnibus is laid up for overhauling and repair vary very much, and naturally depend largely upon the design and workmanship. The Author has taken out the running of ten separate types of omnibuses, one of these being steam-driven and the rest petrol-driven, and has lettered them A to J, B being those steam-driven. The total number of full days of working being known, and the average mileage being taken at 120 miles, the total mileage thus calculated is given in the third column. It will be seen that on the average of the whole an omnibus is on the road 250 days out of the 365 days, and in these 250 days it runs 30,000 miles. In some cases, notably with steam-omnibuses, 33,600 miles has been reached, owing to their having been kept on the road for a larger number of days. These figures are used in Tables IVA and IVB in working out the mileage-cost. The Author has worked out the mileage-cost as it is, and has added in Table IVA the figures to which the several items in the working-cost are believed to be reducible in the future. The present and the future figures are the same, except as regards the items that are rapidly being affected by improvements in design, namely, the fuel-consumption, the cost of lubrication, tire-repairs, and repairs and maintenance. In this Table the wages and fuel items may be taken as practically correct, although in some cases the fuel item has been less than is shown, owing to favourable contracts entered into before the price of petrol was raised. Tire-repairs also began at 2*d.* per mile and are now somewhat less;

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and it is stated with confidence that the figure named in the column, 1¾*d.* per mile, will be reached very shortly.

The maintenance-cost, which is of much importance, was very difficult to obtain accurately, owing to the fact that in some cases it was understated, while in other cases it was overstated, owing to alterations and improvements being charged to revenue instead of to capital.

The depreciation-figure is taken on the supposition that the whole of the omnibus will last 5 years. It is probable that the coachwork will last for a longer period, though in many of the omnibuses first put into service it will certainly not last longer than 3 years. It is reasonable to believe, however, that the bodies of those now running will last the full 5 years.

The results show that, under present conditions, a fair average cost of working a London omnibus may be taken at a little over 10*d.* per mile, and that in the immediate future this figure may be cut down to somewhat less than 9*d.*

In the country these figures must be modified. As already mentioned, it is not the custom to work country omnibuses with two shifts of men; and both drivers and conductors are paid at a lower rate. On the other hand, not only the quantity but the cost of fuel is considerably higher; tire-repairs cost more; so do maintenance and repairs, due to rough roads. Depreciation and most of the other items require no special notice, other than that, in the country, the cleaning of the omnibuses is generally done by the conductors. For country working the cost works out at a little under 1*s.* 1*d.* per mile.

It is only fair to say that some of the railway-companies have got better results as regards mileage from the fuel, and have themselves introduced considerable improvements in the vehicles, which have resulted in greatly reduced maintenance-charges.

The results indicated by these Tables are summarized hereunder for direct comparison.

It will be seen that, per train-mile—if such an expression may be allowed—the traction-engine and the privately-owned petrol-driven motor-car cost practically the same, and that the highest cost of all, per train-mile, is for the small tractor drawing small loads; but it is only fair to say that this is due to the long hours occupied in collecting and distributing the market produce, and that even in this case great economy has been shown when compared with the previous cost of haulage by horses.

It will be noticed that the cost per net ton-mile is confined to the last five vehicles, which are not fitted with elastic tires. The

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first five vehicles have elastic tires, which accounts for a very considerable portion of their total working-costs; but, as has been stated, if it were not for the use of these tires, fast self-propelled traffic would not be permitted on the roads, on account of the noise and of the damage done to the surface of the roads by the hammering action of rigid tires at high speeds.

Table.	——	Per Annum. £ s. d.	Per Mile. d.	Per net Ton-mile. d.
I.	Private motor-car, petrol-driven .	300 0 0	14·40	..
II.	Private motor-car, steam-driven .	175 12 6	7·36	..
III.	Motor-cab electrically-driven . .	301 10 0	6·02	..
IVA.	Motor-omnibus in London . . .	1,284 0 0	10·27	..
IVB.	Motor-omnibus in country . . .	863 0 0	12·94	..
V.	Petrol-driven motor-wagon, 5-ton loads	553 12 0	9·47	3·79
VI.	Large motor-wagon, 8-ton load, 5 on wagon, 3 on trailer. Average results	420 6 0	7·13	1·78
VII.	Large motor-wagon, 8-ton load, 5 on wagon, 3 on trailer. Best results	340 0 0	5·93	1·50
VIII.	Traction-engines drawing 20-ton loads in three wagons. . . .	500 0 0	14·49	1·01
IX.	Small tractor drawing 6-ton loads, all on trailer wagon	340 0 0	15·38	3·28

In conclusion, although the Author has attempted to bring together, for the benefit of the engineering profession, a mass of information, yet he feels that limits of time and space have obliged him to omit many interesting matters on which discussion is likely to arise. For instance, very little has been said on the subject of spring-wheels and on the allied matter of "pedrails," or walking machines. Although much may be obtained from the development of inventions in that direction, yet none of them have as yet been brought sufficiently into general use to warrant their inclusion in this Paper, which deals with results actually obtained.

The Paper is accompanied by four drawings, three tracings, and twenty-three sunprints, from which Plates 1–3 and the Figures in the text have been prepared.

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PART II.—DESCRIPTIONS AND WORKING-COSTS OF VEHICLES.

A.—Description of Typical Motor-Vehicles.

Petrol-driven Private Motor-Car, 1906 Pattern.

(Figs. 1, Plate 1.)

General.—The arrangement of this car follows the usual lines of a chain-driven car, the four-cylinder vertical engine being mounted in the front, with the radiator and fan in front of it. The transmission is by sliding spur-gears and bevel-gearing to chain-pinions, driving chain-wheels mounted on the rear road-wheels.

Engine (*Figs. 1a*, p. 44).—The four-cylinder vertical engine has cylinders of 124 millimetres (4·88 inches) bore and a stroke of 150 millimetres (5·94 inches). The cylinders are cast in pairs with the valve-box, compression-chamber and water-jacket in one piece. Both the induction- and exhaust-valves are on one side of the engine and slope inwards at the top so as to reduce the compression-space. They are operated directly by one cam-shaft without any rocking-gear, etc.

Carburettor.—The carburettor is of a design which gives the correct mixture at every position of the throttle-valve. The throttle-valve and the ignition-gear are connected by a special arrangement of levers, which is so designed that, the ignition-control being coupled to the throttle, the time for ignition is correct for all positions of the throttle-valve when the engine is working at full load. One lever thus controls the engine.

The ignition-distribution is in the high-tension circuit, and only one coil is used for the four cylinders. In some cases high-tension magneto-gear may be fitted as an extra.

Pump.—Water-circulation is maintained through the engine by a spur-gear type of water-pump, which is driven directly from the end of a lay-shaft, on the opposite side of the engine to the cam-shaft, which also drives the magneto when fitted.

Radiator.—The radiator is of the gilled-tube type, tubes fitting at the top into a cast aluminium tank of special design, and at the bottom into a sheet-copper tank. A fan of large diameter is mounted behind the radiator, and is driven from the front of the engine.

Clutch.—Of the ordinary metal or leather type, spring-controlled. A special feature is the ease with which it can be dismantled, and the tension on the spring adjusted.

Gear-Case (*Figs. 1b*, p. 45).—The aluminium casing surrounding the gears is extended on either side around the cross shafts, and is supported by a bracket from the frame, close up to the chain-pinions, and at one point at the rear of the case, thereby ensuring self-alignment under all conditions.

From the drawing of the case it will be seen that four speeds and a reverse are provided, and no direct-drive is given on any gear. The gears are arranged on

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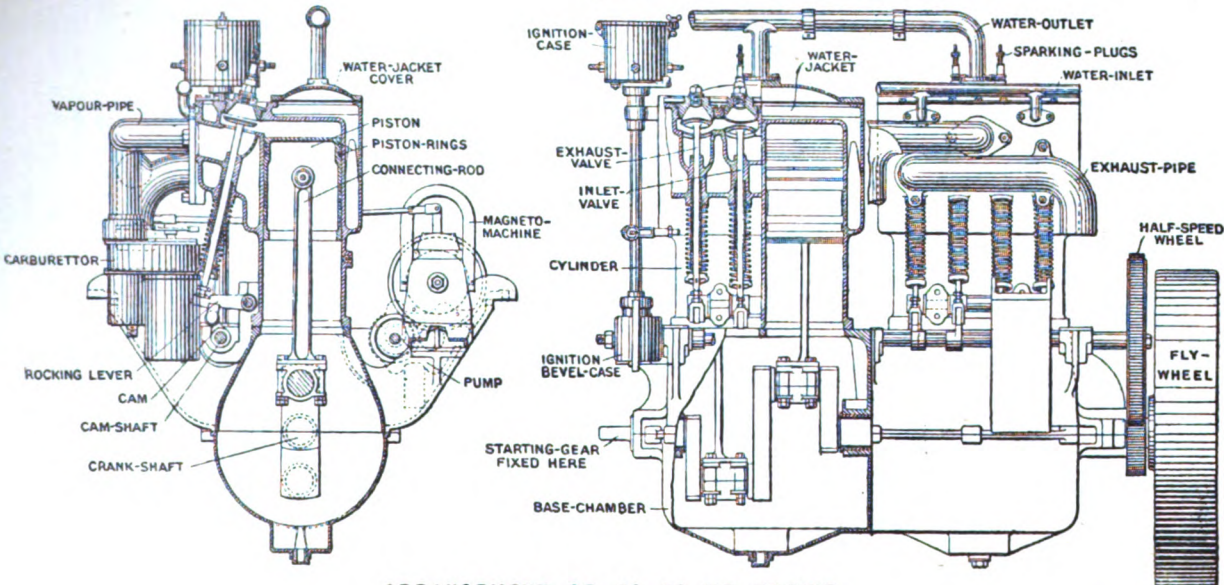
Figs. 1a.



ARRANGEMENT OF 30-40 HP. ENGINE.

BORE = 124 MM (4·88 INS.) STROKE = 150 MM (5·94 INS.)

Scale: 1 Inch = 1 Foot

INCHES 12 9 6 3 0 1 2 FEET

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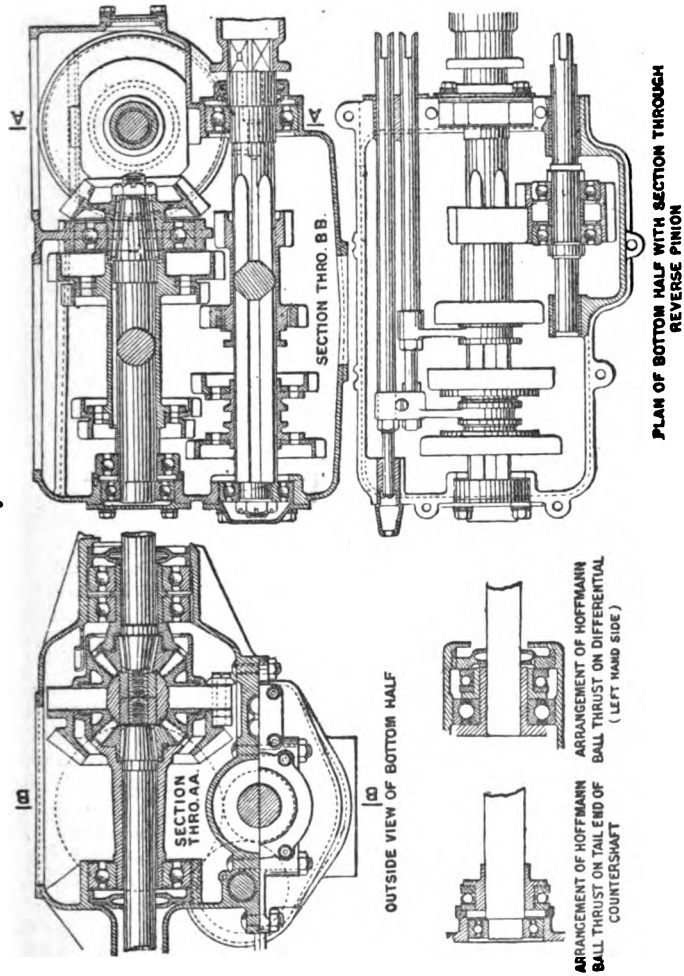
the two-sleeve principle, making a short and compact case. Ball-bearings are provided throughout.

Speed-Control.—A special form of "gate" control is provided, with a separate lever for the reverse gear.

Figs. 16.


SECTION THRO. BB.
PLAN OF BOTTOM HALF WITH SECTION THROUGH REVERSE PINION
SECTION THRO. AA.
OUTSIDE VIEW OF BOTTOM HALF
ARRANGEMENT OF HOFFMANN BALL THRUST ON DIFFERENTIAL (LEFT HAND SIDE)
ARRANGEMENT OF HOFFMANN BALL THRUST ON TAIL END OF COUNTERSHAFT

Axles.—The front axle is a high-grade steel forging of H section in one piece. The axle-swivels are of a type in which the jaw is on the axle. The back axle is made from a straight steel bar, machined out to H section. Ball-bearings are used in the hubs of both back and front wheels.

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Brakes.—Two pairs of brakes are fitted, one pair consisting of steel bands tightening on drums mounted by the side of the chain-pinions on the ends of the cross shafts. With this method no pressures from the brakes are taken through the transmission-gear, except through the driving-chains. Duplicates of these brakes are applied to drums on the rear road-wheels. Both brakes are compensated.

Steering-Gear.—The steering-gear is of the irreversible worm-and-segment type, having the single engine control-lever referred to above working on a fixed quadrant on the top of the steering-wheel.

Petrol-Tank.—The tank has a capacity of about 20 gallons and is carried inside the body under the rear seats. Pressure feed is used, the pressure being maintained from the exhaust-gases.

Frame.—The frame is of the armoured wood type, of special construction, which allows the width to be reduced in front without weakening the main strength member. No underframe is used, the engine and transmission-gear being bolted directly to the main frame.

The dimensions of this chassis are :—

	Feet.	Inches.
Wheel-base	10	0
Wheel-gauge	4	6
Width of frame	2	8
Length behind dash-board available for body space	9	0

Steam-driven Private Motor-Car, 1906 Pattern.

(Fig. 2, Plate 1.)[1]

General.—The arrangement of this car to some extent follows the lines of a petrol-driven car, the two-cylinder vertical compound steam-engine being mounted at the front of the car with the condenser and fan in front of the engine. The transmission is by Cardan shaft and bevel-gear to a live back axle carrying the differential gear and rear driving-wheels.

Engine.—The two-cylinder compound vertical engine has a high-pressure cylinder 3 inches in diameter, a low-pressure cylinder 5 inches in diameter, both of 3½ inches stroke. The cylinders are cast as a pair, with the valve-chest between them. The high-pressure valve is a piston-valve, and the low-pressure a slide-valve. The valves are operated by link-motion and eccentrics in the usual manner.

Generator.—The generator consists of eleven flat coils of steel tubing. These are coupled in series, the steam passing to the engine from the hottest coil.

Burner.—The burner consists of a casing in which a suitable mixture of vaporized fuel and air is burnt, the supply of fuel and the temperature attained being controlled by a thermostat regulator. The vaporizing of the fuel is carried out in a vaporizer which, at starting, can be raised to the proper temperature by a pilot-light and maintained at that temperature by the same pilot-light when the engine is standing.

The speed of the car is controlled by a throttle-valve worked by a hand-wheel placed immediately above the steering-wheel, but all other adjustments as to

[1] This illustration is diagrammatic.

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water- and fuel-supply are controlled by automatic devices and do not call for any attention on the part of the driver.

These automatic devices consist of a water-regulator controlled by the steam pressure, a thermostat or temperature-regulator controlled by the heat of the fire, and a flow-regulator acting in combination with the two other devices, which ensure that the water and fuel is so proportioned at all times that no matter what the demand for steam may be, an approximately constant pressure and constant temperature are maintained at all times, and that the generator can never be flooded with water nor the burner be flooded by excess of fuel. Abnormally high pressures can never be obtained, and when the engine is at rest the fuel-feed is essentially nil.

The condenser is of the gilled-tube type having vertical tubes. The exhaust steam, having previously passed through a feed-water heater, is condensed, and under favourable circumstances a partial vacuum is obtained.

Brakes.—Both the foot- and the hand-brake act direct on the rear wheels.

Axles.—Both axles are straight and ball-bearings are used throughout.

Tanks.—The water-tank is laid in front on the dashboard and is readily detachable. The fuel-tank is at the back, thoroughly protected from injury, as its lowest point is above the level of the back axle.

The normal fuel-consumption under touring conditions, when the car is fully loaded, is 1 gallon of benzine or paraffin per 14 miles.

Modern Electrically-Driven Motor-Cab.

(Figs. 3, Plate 1.)

The Figures show the general arrangement of this patented chassis, to which any style of body can be adapted.

General Dimensions:—

	Feet.	Inches.
Over-all length	10	6
Wheel-base	6	6
Over-all width	5	6
Height of chassis	2	2
Width of frame	3	1

Weight.—The weight of the chassis, complete with battery, is 22 cwt.

General.—The arrangement of this chassis follows the usual practice adopted by the leading automobile engineers in chain-driven cars, with the difference that the chains are enclosed in dust- and oil-tight gear-cases, which are provided with a means for taking up the slack of the chains without removing the gear-cases. The power is transmitted from the motor-armature spindle to an intermediate shaft by means of a silent chain, and thence by chains to the sprockets on the rear wheels, giving a total reduction of 7·8 to 1. To reduce the noise caused by the chains the out end pinions are of vulcanized fibre.

Frame.—The frame is of pressed steel with stamped steel scroll-irons and spring supports.

Axles.—The front axle is a steel stamping of H section in one piece. The back axle is of nickel-steel.

Wheels.—The wheels are of the artillery type, with bent ash felloes and oak spokes, fitted with 820 × 120-millimetre (32·3 × 4·72-inch) tires, and are mounted on steel hubs with double ball-bearings.

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Springs.—The springs are semi-elliptic, 44 inches long, suspended by shackles at each end, provided with lubricators.

Brakes.—Three brakes are provided :—

(*a*) A pair of internal expanding brakes fixed to the hubs on the hind wheels.

(*b*) An external band-brake operating on the armature-shaft.

(*c*) An electric brake obtained by reversing the current in the armature.

(*a*) and (*b*) are operated by foot-pedals and (*c*) by the controller.

Steering.—Steering is effected by means of a cut rack and pinion, which moves the connecting-rod joining the steering-levers by a diagonal rod with ball- and socket-joints at each end This provides an exceptionally full lock, it being possible to turn the car in a circle, the radius of which is 12 feet 6 inches.

Motor.—The motor is of the enclosed type, the coils being series-wound with flexible cable. The armature is former-wound ; the commutator has forty-one sections of hard drawn copper, provided with twin carbon brushes. The magnet covers are of aluminium fitted with ball-bearings, in which the armature-shaft revolves.

Battery.—The battery consists of forty-four cells of a patented pasted type in ebonite containers, carried in a stout teak case provided with spring contacts, so that, when empty, the battery can be readily disconnected and exchanged for a fully charged set. The battery has a capacity of 150 ampere-hours on a 4-hours' discharge. The weight of each cell is 24 lbs.

Controller.—The controller is erected round the base of the steering-pillar. The usual wooden roller is dispensed with, only mica or other non-inflammable insulation being used. The contacts are of phosphor-bronze of suitable dimensions.

Speeds.—Four speeds are provided—4, 6, 10 and 14 miles per hour—and two reverse speeds, the electrical coupling arrangements being as follows :—

(1) Battery in two parallels, giving 44 volts, with resistance in the motor-circuit.

(2) Battery the same as in (1), with resistance cut out.

(3) Battery in series, giving 88 volts, with resistance in the motor-circuit.

(4) Battery the same as in (3), with resistance cut out.

To reverse the car the direction of the current in the armature is reversed.

Instruments.—A combined moving-coil, D'Arsonval type, of volt- and ampere-meter is provided. A four-pole cut-out, which disconnects the battery, is also provided, operated by the foot.

Lighting.—The vehicle is provided with two electric side-lights and one tail-light, also one inside light, all provided with suitable switches and fuses.

Current-Consumption.—The current-consumption of these vehicles at 15 miles per hour on a level hard road, with solid tires, is 30 amperes at 88 volts.

Petrol-driven Motor-Omnibus Chassis.

(Figs. 4, Plate 1.)

This chassis is chosen as being typical of present-day practice in motor-omnibus chassis construction. The frame is of channel steel 4½ inches deep by ½ inches wide.

Engine.—The engine has four vertical cylinders, 4⅝ inches in diameter by 5½ inches stroke. The cylinders, combustion-chamber, valves and barrels are water-cooled, the water-jacket being of such a length that the piston-rings do not at any part of the stroke pass below the water-jacket. The inlet- and exhaust-valves are of nickel-steel. They are mechanically operated, being worked by separate cam-shafts. Low-tension magneto-ignition is fitted.

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The normal speed of the engine is 900 revolutions per minute, but it may be raised to 1,250 revolutions and reduced to 200 revolutions, per minute. The power developed at 1,000 revolutions per minute is about 35 B.HP.

Circulating-Pump.—The pump is of the centrifugal type, gear-driven. The main water-pipes are 1 inch in internal diameter.

Radiator.—The radiator is of the gilled-tube type, draught being induced by means of a fan.

Clutch.—The clutch is of aluminium, of the ordinary cone pattern, shod with leather. The controlling spring is apart from the clutch, and is easily accessible for adjustment. Between the clutch and gear-box a double universal joint is provided, with a view to prevent undue strains from being set up when travelling over rough roads.

Transmission-Gear.—The change-speed gear is on the Panhard system, giving three changes of speed forward and a reverse, all speeds being operated by a single lever. The gear-box is of aluminium and is fitted throughout with ball-bearings. The thrust from the propeller-shaft is taken up and transmitted direct to the frame by means of a spherical thrust-block, which also makes a three-point support to the back axle.

The power is transmitted from the propeller-shaft by a bevel-pinion engaging with a bevel-wheel bolted to the differential gear-box, which is situated in the centre of the back axle-casing, and from there to the spur-wheels fitted on the inner ends of each axle-arm, giving a reduction of 9 to 1 in the axle gear-box.

Control.—The speed of the engine is controlled by means of a lever fitted in a convenient position operating the throttle-valve. When the clutch is taken out, the throttle is automatically closed, and cuts the engine-speed down to about 200 revolutions per minute. One lever only is employed to operate the change-speed gear, this lever operating all three forward speeds and the reverse.

Road-Wheels.—The wheels are of the "Composite" pattern, fitted with any kind of tire required.

Springs.—In addition to the usual side springs a cross spring is fitted connecting the hind ends of the back springs.

Brakes.—Double-acting brakes are fitted, one on the gear-shaft and one operating on the road-wheels, the gear-shaft brake being actuated by a push pedal. The side brakes are of the internal expanding type actuated by a hand-lever, and are compensated so that the pressure on each is equalized.

Steering-Gear.—Steering-gear of the Ackermann type with the usual worm and segment is employed, enclosed in an oil-tight box.

Petrol-Tank.—The petrol-tank is placed under the driver's seat, is cylindrical in form, and has a capacity of 24 gallons.

Steam-driven Motor-Omnibus Chassis of the Serpollet Type.

(Figs. 5, Plate 1.)

This chassis is typical of the latest practice in steam-driven motor-omnibuses.

The frame is of channel iron 5½ inches deep, and is strengthened by cross bracing at the rear end as well as by corner pieces.

The engine (*Fig. 5a*, p. 50) has two double-acting cylinders 3½ inches in diameter by 5 inches stroke. Special pains are taken to isolate the glands in order to prevent the escape of steam into the crank-chamber containing the working parts.

On account of the high pressure of steam used, 550 lbs. per square inch, the

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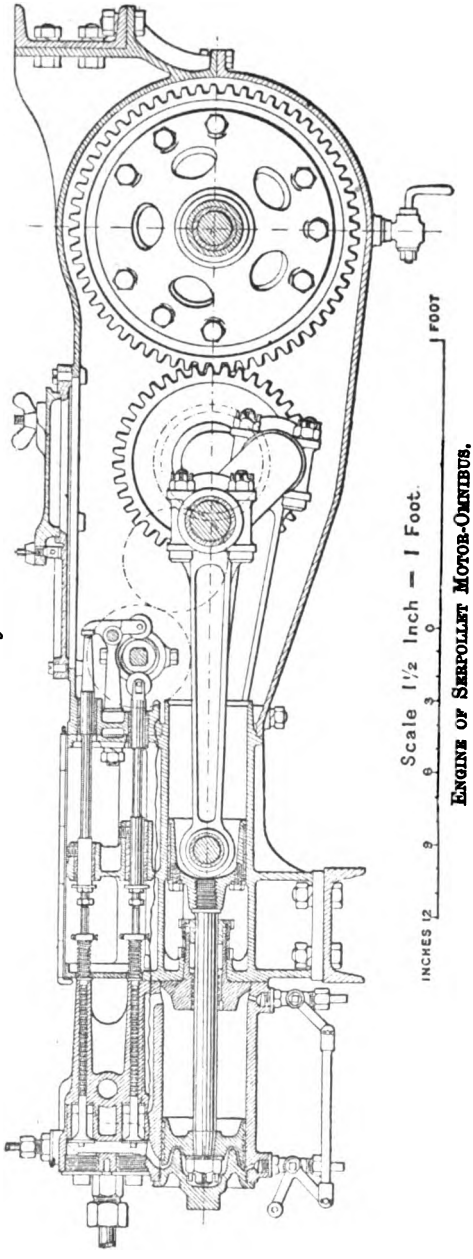

Fig. 5a.

ENGINE OF SERPOLLET MOTOR-OMNIBUS.

whole of the parts, *i.e.*, piston-rods, crank-shaft and bearing surfaces, are of unusually large dimensions for this size of cylinder.

The distribution of steam is carried out by lift-valves operated by cams on a cam-shaft. The position of the cam-shaft is controlled from the steering-column by a lever, so that the cams can give a cut-off ranging from quarter-stroke up to half-stroke on the forward gear, but only one fixed cut-off of half-stroke on the reverse gear. The speed of the omnibus is controlled by a throttle-valve pedal, whereas the steam-pressure necessary to obtain the power can be varied by altering the speed of the donkey-pump by a lever also fixed to the steering-column.

The normal speed of the engine at the legal limit of 12 miles per hour is 300 revolutions per minute. It is geared down to the back axle by spur-gearing between the crank-shaft and the countershaft, on which is mounted the differential gear.

The countershaft is geared to the driving-wheels by side chains, the sprockets on the countershaft having nine teeth against thirty teeth on the hub-rings.

The steam, after leaving the exhaust ports, passes through feed-water heaters placed on each side of the engine; thence

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it passes to the condenser shown in the front, and afterwards to a second condenser in the rear, and finally to the water-tank. The feed of both oil-fuel and water is controlled by a steam-driven donkey-pump.

Starting is effected by a hand-socket lever. After a few strokes the hand-lever can be removed and then the valve of the donkey-pump may be opened. This donkey-pump has two pump-barrels, one above the other, the top one being of small diameter for the oil-supply to the burner, the lower one being the donkey-feed. The pumps are usually set for a fixed proportion of 10 of water to 1 of fuel. Attached to the donkey-pump is an oil-pump for the lubrication of the working parts.

The road-wheels, springs, brakes, and steering-gear do not differ greatly from those of the typical petrol-driven motor-omnibus, except that the power of reversing this engine enables the steam to be used as a very powerful emergency brake.

The fuel-consumption of this motor-omnibus is stated to be remarkably low, namely, 1 gallon of ordinary paraffin per 6 miles.

Modern Steam Motor-Wagon, fitted with Horizontal Locomotive Boiler.

(Figs. 6, Plate 2.)

General.—This wagon is capable of carrying 5 tons and drawing behind it 2 tons on a trailer at a speed of 5 or 6 miles per hour, up gradients of 1 in 7 on medium road-surfaces. The loading-platform is 11 feet long by 6 feet 6 inches wide, the sides are 1 foot 6 inches deep.

Boiler.—The boiler is of the horizontal locomotive type, made throughout of Siemens mild steel hydraulically tested to 350 lbs. per square inch, the working steam-pressure being 200 lbs.; the fire-box is made specially large for easy steaming with coal, coke, or wood-fuel. The total heating-surface in fire-box and tubes is 90 square feet.

Engine.—The engine is compound; the dimensions of its cylinders, which are steam-jacketed, are:—H.-P. 4 inches, L.-P. 6½ inches, by 7 inches stroke. It is fitted with a high-pressure gear whereby it can be instantly converted into a double high-pressure engine, each cylinder receiving steam separately from the boiler and exhausting independently into the funnel; this almost doubles the power of the engine for ascending very steep inclines, and also makes it much handier for working in awkward places, as no reversing is required.

Gearing.—Two speeds are arranged, 3 miles and 6 miles per hour, and are interchangeable by one lever on the foot-plate. The driving is done by steel cut gearing from the crank-shaft, which is perfectly balanced, to phosphor-bronze gearing on a fixed stud-shaft, and thence by a strong roller-chain to compensating gear on the main axle.

Wheels.—The road driving-wheels are 3 feet 6 inches in diameter by 10 inches on the face; the front wheels are 2 feet 9 inches in diameter by 6 inches on the face.

Brake.—An efficient hand-brake is fitted to work on a large hub, which is keyed on the main axle.

Water-Tank and Fuel-Bunker.—The water-tank holds 170 gallons, and is sufficient to take the full load 15 to 20 miles on good roads. The fuel-bunker will hold sufficient for a 40-mile run.

Injectors.—Two injectors are fitted.

Water-Lifter.—A water-lifter is fitted, with 24 feet of suction-hose.

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Bearings.—All bearings are of phosphor-bronze, and the engine is automatically lubricated throughout.

All starting-, steering-, reversing- and gear-levers are within easy reach of the driver.

Steam-driven Motor-Wagon, fitted with Vertical Boiler.

(Figs. 7, Plate 2.)

General.—The carrying-capacity on good macadam or paved roads, and on gradients not exceeding 1 in 8, is 5 tons, and 2 tons on a trailer.

The platform-dimensions can be varied up to 13 feet in length by 6 feet 6 inches wide. The general dimensions are :—

Length over all	18 feet 9 inches.
Width „ „	6 „ 6 „
Height over chimney	8 „ 9 „

Engine and Transmission.—The engine and the change-speed and compensating gear are self-contained in a dust-proof and oil-containing casing. The power of the engine is 35 I.HP., and it is fitted with a constant-lead valve-gear.

The Joy valve-gear has been adopted, with the slide-valves on top of the cylinders, thus enabling a much shorter and stiffer crank-shaft to be used than would otherwise be the case.

The average working-speed with full load on the level is 5 to 6 miles per hour.

The bearing-surfaces being of unusual dimensions, adjustment is rendered unnecessary and great simplicity and security are thus obtained. The lubrication of the parts inside the casing is of the simplest possible description. The casing is charged with oil, the amount being fixed by the opening of a test-cock on the side of the casing. The cylinders are lubricated by a positive sight-feed lubricator, with a duplicate system of feed in case of the glass breaking.

Locking-Gear.—The compensating gear is designed so that it can be locked, in order that both wheels may become drivers, as occasion may demand.

Boiler.—The boiler is of the fire-tube central-feed type, built for a working steam-pressure of 200 lbs. per square inch. A distinguishing feature of the boiler in this case is the ease with which it can be taken to pieces for examination and cleaning.

Boiler-Feed.—The boiler is fed by a ram pump, which runs at practically a constant speed, irrespective of the speed of the vehicle. This pump can be run when the vehicle is stopped. For the auxiliary feed-supply an improved automatic injector is used, with independent suction.

Wheels.—The wheels are of the "Composite" pattern, said to possess all the advantages of the gun-carriage pattern whilst dispensing with loose hubs and spokes. The driving-wheels are 3 feet 6 inches in diameter by 10 inches wide, and the steering-wheels are 3 feet in diameter and 6 inches wide. The tires are of weldless steel, hydraulically fitted.

Brakes.—Internal brakes, protected from dirt, are fitted inside the chain-rings.

Water-Tank.—The water-tank has sufficient capacity for a run of 12 to 20 miles, according to the nature of the roads.

Fuel.—Coke or hard Welsh coal can be used. The bunker-capacity is sufficient for an ordinary day's working.

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STEAM-DRIVEN MOTOR-WAGON, FITTED WITH VERTICAL BOILER, USING SUPERHEATED STEAM, WITH EXTRA LARGE CYLINDERS AND SMALL GEAR REDUCTION.

(Figs. 8, Plate 2.)

General Dimensions:—

	Feet.	Inches.
Length over all	18	3
Width „ „	7	0
Height „ „	8	9
Height of platform, loaded	3	7
Wheel-base	9	0
Rear wheel-gauge (between tire-centres)	4	9
Area of platform	83 sq. ft.	

Carrying-Capacity.—Six tons up a gradient of 1 in 8. It will draw a trailer loaded with 4 tons, making a total of 10 tons carried.

Boiler.—The boiler (*Figs. 8a*) is designed for a working-pressure of 250 lbs. per square inch. The heating-surface is 61·3 square feet and the grate-area 3·6 square feet. It is cylindrical, placed vertically, with cross water-tubes, fired from the top through a shoot formed centrally between the cross tubes. The tubes, forty-eight in number, are 1¾ inch in external diameter. Under test, an evaporation of 7·78 lbs. of water per pound of coke, equivalent to 16·38 lbs. per square foot of heating-surface has been obtained. A superheating coil is placed in the smoke-box, of sufficient surface to superheat the steam about 100° F. The working-level is far above the tube-ends, and is such that the steepest gradients may be climbed without exposing the crown, which, as a safeguard in the event of the water-level accidentally falling too low, is fitted with a fusible plug. It will be seen that by slacking the upper and lower shell-bolts the fire-box may be dropped through the outer shell without disturbing any connections on the latter, all the surfaces being then perfectly accessible for cleaning.

Boiler-Feed.—The boiler is fed either by injector or by a feed-pump driven off the engine crank-shaft.

Stop-Valve.—The stop-valve (*Fig. 8b*) calls for special mention. It is combined with a throttle and foot release-valve. The stop-valve is opened fully by one turn of a horizontal lever. Should the driver wish to stop instantly in traffic, he depresses the pedal which at once releases the steam from the engine. In going down-hill the engine is reversed, and, acting as a compressor, is eased down the hill by pressing the foot-valve and at once stopped by lifting the foot.

The road-wheels of a wagon at 6 miles per hour run at about 48 revolutions per minute, and the makers of this wagon, rather than fit a high-speed engine and reduce the speed through gearing to the driving-axle, have put in an amply powerful engine and saved the greater part of the reduction. The weight of this engine is, however, still less than that of the ordinary high-speed engine plus countershaft and change-gears.

Fig. 8c shows the arrangement of the parts. The engine has two cylinders 6¾ inches in diameter by 10 inches stroke. Separate poppet-valves for the distribution of steam and exhaust are placed below the cylinders at each end, and are actuated by a hardened steel cam-shaft running in an oil-bath and positively driven from the crank-shaft through machine-cut bevel-gears. Axial movement of the cam-shaft permits of three different periods of steam cut-off being obtained, from one-quarter to three-quarters of the stroke for forward gear. One set of cams only is used for reverse gear. This valve-gear permits

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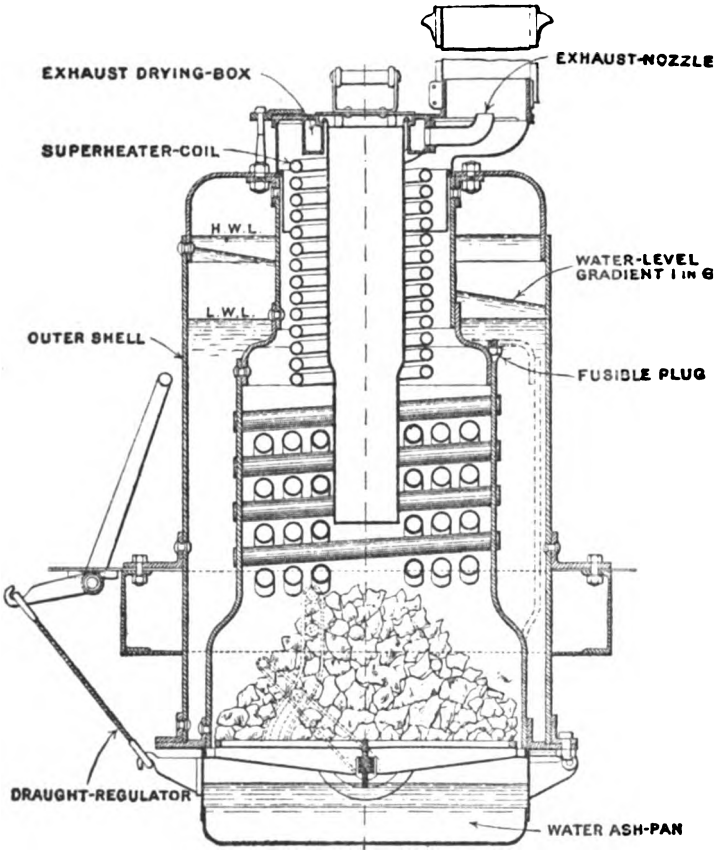
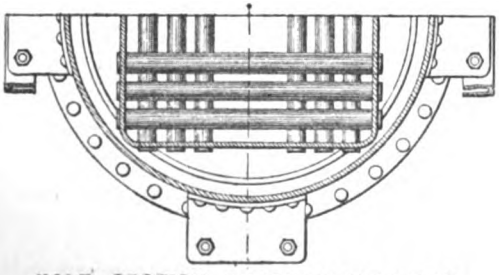
Figs. 8a.





HALF SECTION THROUGH FIRE-BOX.

Scale ¾ Inch — 1 Foot.

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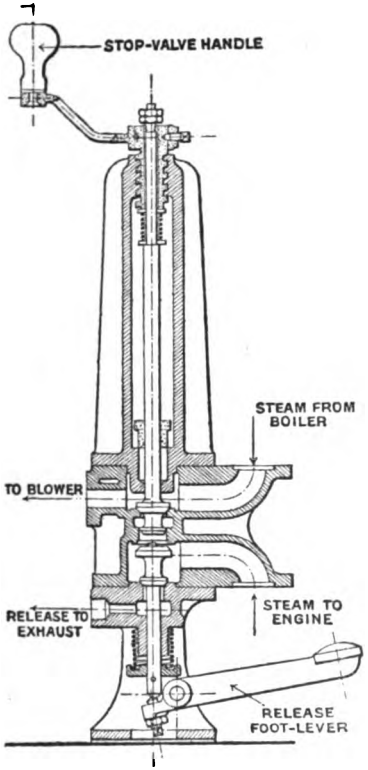
of the use of high-pressure superheated steam in a simple engine with perfect absence of leakage past the valves or from steam to exhaust.

The engine will develop economically up to 50 HP., and at the rate of 70 HP. when climbing hills. The range of power is thus large, the result being that no change-gear is required.

Rear Axle.—The rear axle is a nickel-steel forging 5 inches in diameter at the journals, which are oil-reservoir journals protected from dust. The differential gear-wheels are enclosed in dust-proof casings and run in oil. One of the differential bevel-wheels is shrunk and keyed on the axle, the other being

Fig. 8b.



bolted to a bronze bushed mild-steel sleeve, to which is bolted the off-side road-wheel centre, and which runs loose on the axle.

The two driving-wheels may be locked, so as to work in unison, by a steel pawl pivoted to the hub of the off-side driving-wheel with a notched disk keyed to the axle (*Fig. 8d*).

Front Axle.—The front axle is a forging 3 inches square, on each end of which are formed bronzed bushed eyes for the steering-pivots. The front wheels are pivoted to the axle on the centre line of the wheel-treads, ball thrust-bearings being introduced to the pivots (*Fig. 8d*). This idea has been realized

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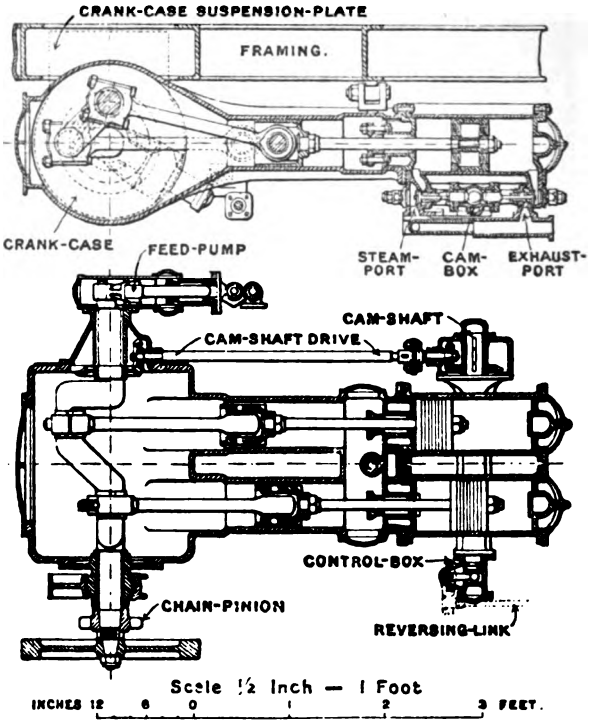
by dishing the centres of the front road-wheels. The advantages are said to be: perfect ease in steering, the front wheels being swung about the centre line of the treads and not traversed; the axles are truly loaded about their centres; striking an obstacle with the front wheels throws no strain, through the steering-gear, on the hand-wheel screw.

Steering-Gear.—Ackermann steering-gear is used, the steel screw working in an oil-bath.

Road-Wheels.—The four road-wheels (*Figs. 8d and 8e*) are of a cushioned adjustable form. The front wheels are 34 inches in diameter by 5¾ inches wide. The rear wheels are 40 inches in diameter by 10½ inches wide. The centres are

Fig. 8c.



steel castings, the felloes of oak, and the tires of weldless steel. An interesting feature of these wheels is that stretching of the tires or shrinkage of the wood felloes is easily followed up by adjusting the coned felloes on the metal centres. The metal tires with their felloes may be bodily removed in a very short time and special winter tires may be substituted when conditions of weather demand it; or when worn out the tires may be removed and renewed without adopting the troublesome method of hydraulically pressing or shrinking.

Frame.—The chassis frame is built of steel channel-bars 7 inches deep by 2½ inches wide, metal ⅜ inch thick, strongly braced by gusset-plates and angle-knees, the whole being fastened by steel bolts.

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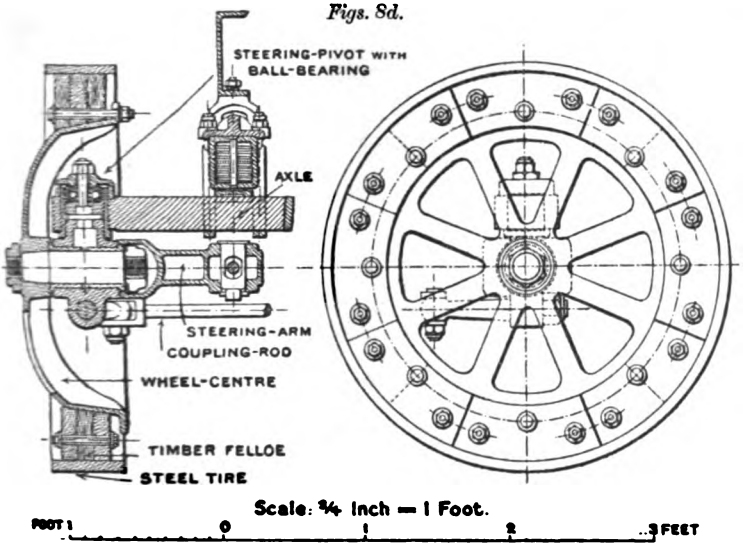
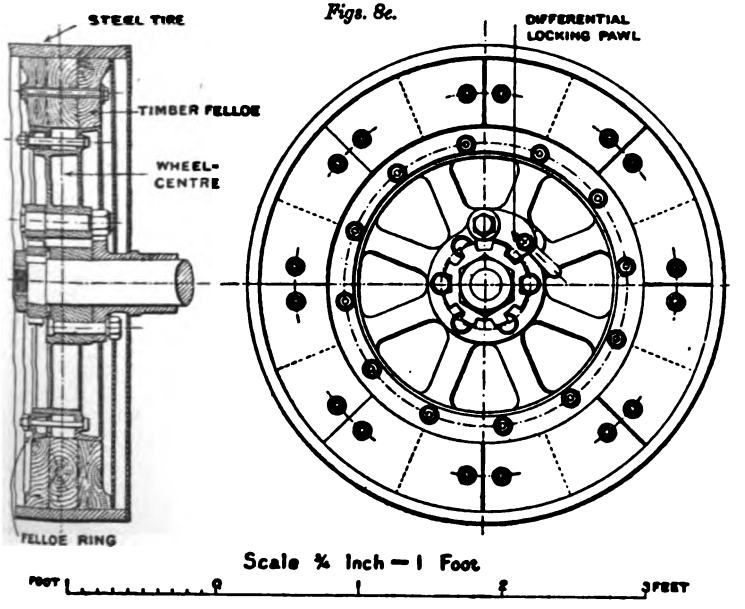
Suspension-Gear.—The bearing-springs are placed directly under the frame.

Figs. 8d.



Figs. 8e.



Spring eyes are bronze bushed and secured to slippers by hardened steel pins

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jointed to machined slippers which are free to slide radially as well as axially in machined guides.

The thrust from the rear axle to the frame is taken by steel radius-rods and nuts.

Water-Tank.—The water-tank has a capacity of 184 gallons. It is fitted with the usual water-lifter and hose.

Lubrication.—Every working joint and surface is provided with a special grease-cup accessible from the outside of the chassis.

Brake-Gear.—A screw compensating brake-gear, worked from the driver's seat, applies timber blocks to the driving-wheel tires. A supplementary brake is provided by reversing the engine.

Compound Spring-Mounted Heavy Road-Locomotive.

(Figs. 9, Plate 3.)

Boiler.—The boiler is constructed of mild steel with a large fire-box. The longitudinal seam of the boiler-barrel is butt-jointed and double-riveted with inside and outside cover-strips. An extended smoke-box is fitted.

Engine.—The engine is compound, the high-pressure cylinder being 6¾ inches, and the low-pressure 11½ inches diameter by 12 inches stroke. The cylinders are steam-jacketed. An auxiliary self-closing starting-valve is fitted.

Gearing.—The gearing provides for three speeds, and is fitted with a safety-clutch.

Boiler-Feed Arrangements.—These consist of an injector with all usual fittings, pipes, and connections, and also of an independent pump, the latter being also available for filling the tanks.

Wheels.—Wheels of the usual traction-engine type are fitted, the rear or driving-wheels being 7 feet in diameter by 18 inches wide, the front wheels 4 feet 6 inches in diameter by 9 inches wide.

Tanks and Bunker.—The capacity of the water-tanks is 405 gallons, that of the bunker being 8 cwt. of coal.

Brake.—A brake acting direct on to both driving-wheels is fitted.

Winding-Drum.—A winding-forward drum, with 75 yards of steel-wire rope, is fitted.

Compound Spring-Mounted Tractor.

(Figs. 10, Plate 3.)

The weight of the tractor empty is 4 tons 17 cwt., and the weight in working order 5 tons 12 cwt. The tractor is so constructed that it can be registered for use under the Heavy Motor-Car Order, 1904.

Boiler.—The boiler is constructed of mild-steel plates, and is fitted with the Belpaire fire-box and weldless steel tubes. It is designed for a working-pressure of 200 lbs. per square inch.

Engine.—The engine is compound, the three cylinders being 3½ inches, 3½ inches and 7 inches in diameter respectively, all with a stroke of 8 inches; the cylinders are steam-jacketed. The three cylinders consist of one high-pressure cylinder and two low-pressure. The large low-pressure cylinder is placed alongside the high-pressure cylinder, and the small low-pressure cylinder is placed tandem with the high-pressure and works on the same crank.

The object of this arrangement is to increase the ratio of expansion and equalize the power of each crank. In consequence of the narrow width available on these tractors, it is impossible to use a low-pressure cylinder, of the requisite area, placed alongside the high-pressure cylinder.

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The other advantages obtained by the arrangement are that, when the starting-cock for admitting high-pressure steam into the low-pressure cylinder is opened, the engine immediately works as a double-cylinder engine, the high-pressure cylinder being merely converted into a differential cylinder, and the two low-pressure cylinders working as a double-cylinder engine with boiler steam-pressure. The arrangement also provides for double the number of exhaust blasts in the chimney, and therefore ensures better draught and a brighter fire in the fire-box, and at the same time the noise of the exhaust is deadened.

The brackets for carrying the crank-shaft and second-motion shaft are formed in one casting, the bottom portion of which (together with the side frame of the engine) forms an oil-tight casing for the motion-work, allowing for splash lubrication.

Walschaert valve-gear is used, the valve eccentric tumblers being formed solid with the crank-shaft; slide-valves and nuts are of gunmetal.

Gearing.—The gearing is arranged for two speeds: slow, 2 to 3 miles per hour; fast, 4 to 5 miles per hour. The gearing for the first and second motions is of wrought steel with machine-cut teeth; that for the second-motion shaft-pinion, third-motion wheel, road-spur wheel and pinion, and for the differential-gear wheels and pinions, is of cast steel. A special arrangement is provided for locking the differential gear, operated from the foot-plate.

Wheels.—Wheels of the usual traction-engine type are fitted, the driving-wheels being 5 feet in diameter by 8 inches wide, the front wheels being 3 feet 6 inches in diameter.

Tanks and Bunker.—The capacity of the water-tank is 100 gallons, that of the fuel-bunker 3 cubic feet (1½ cwt. of coal).

Boiler-Feed Arrangements.—The boiler-feed arrangements consist of an injector with all necessary connections, and in addition an independent feed-pump with all pipes and connections is also fitted.

Brake.—A screw friction-brake acting direct on both driving-wheels is fitted.

Winding-Drum.—A winding-drum, with 50 yards of steel-wire rope, is fitted. The drum is carried on an independent stud, and is driven from the crank-shaft by means of an upright shaft and bevel-gear controlled from the foot-plate by means of a clutch-lever.

B.—Working-costs of Typical Motor-Vehicles.

Table I.—Working-cost of a 28–30-HP. Petrol-driven Private Motor-Car.

	Per Annum. £	s.	d.	Per Mile. d.
Fuel:—Petrol, 12½ miles per gallon; 5,000 miles per annum, or 400 gallons at 1*s.* 3*d.*	25	0	0	1·20
Stores:—Lubricating-oil, grease, etc.	23	0	0	1·10
Tire replacements and repairs:—Two front-wheel covers and four rear-wheel covers and tubes . .	75	0	0	3·60
Other repairs, including an annual overhaul . . .	72	0	0	3·46
Depreciation at 15 per cent.	105	0	0	5 04
Total	£300	0	0	14·40

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TABLE II.—WORKING-COST OF A 20-HP. STEAM-DRIVEN PRIVATE MOTOR-CA

	Per Annum.			Per Mile
	£	s.	d.	d.
Fuel :—Benzine or paraffin, 14 miles to the gallon ; 5,000 miles per annum, or 357 gallons at 10½d. per gallon	15	12	6	0·75
Stores :—Lubricating-oil, grease, wipers, etc.	8	0	0	0·30
Tire replacements and repairs :—One complete set with spare tubes	36	0	0	1·73
Other repairs, including annual overhaul	33	0	0	1·58
Depreciation—15 per cent. on £550	83	0	0	4·00
Total	£175	12	6	7·36

TABLE III.—WORKING-COST OF AN ELECTRICALLY-DRIVEN MOTOR-CAB.

Average daily mileage	40
Average number of days worked per annum	300
Average annual mileage	12,000

	Per Annum.			Per Mile.
	£	s.	d.	d.
Wages and livery	106	0	0	2·12
Electric current	8	15	0	0·17
Garage, battery attendance, oiling, cleaning, washing, etc.	35	15	0	0·71
Maintenance :—				
Battery	50	0	0	1·00
Tires	30	0	0	0·60
Other repairs	7	0	0	0·14
Rent	6	0	0	0·12
Insurance	11	0	0	0·22
Depreciation, 20 per cent.	75	0	0	1·50
Total	£301	10	0	6·02

TABLE IV.—AVERAGE MILEAGE WORKED DURING THE YEAR 1905–1906 BY MOTOR-OMNIBUSES IN LONDON.

	Engines.	Number of Working Days.	Total Miles run.
A	Petrol	280	33,600
B	Steam	280	33,600
C	Petrol	260	31,200
D	,,	250	30,000
E	,,	240	28,800
F	,,	240	28,800
G	,,	230	27,600
H	,,	220	26,400
I	,,	220	26,400
J	,,	200	24,000
	Average	250	30,000

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TABLE IVA.—WORKING-COST OF MOTOR-OMNIBUSES IN LONDON IN SEPTEMBER, 1906.

Average daily mileage 120
Number of days worked per annum . . . 250
Average annual mileage 30,000

	Per Annum.	Pence per Mile now.	Pence per Mile in Future.
	£ s. d.		
Wages—			
Drivers at 6s. 9d. per shift . . . . }	227 10 0	1·820	1·820
Conductors at 5s. 8d. per shift . . }			
Fuel—			
Petrol, 6½ miles per gallon at 8½d. .	163 10 0	1·305	
Crude paraffin, 5 miles per gallon at 2½d.	..	..	0·500
Lubricants—			
60 miles per gallon at 1s. 4d. . . .	33 0 0	0·264	
360 „ „ „ „ 2s. 4d. . . .	..	..	0·078
Tire repairs—			
By contract	234 0 0	1·875	
„ „	..	..	1·750
Maintenance—			
By contract	225 0 0	1·800	
„ „	..	..	1·400
Depreciation, at 20 per cent.	170 0 0	1·360	1·360
Insurance (fire and third party) . . .	50 0 0	0·400	0·400
Car-sheds	100 0 0	0·800	0·800
Cleaning omnibuses	15 0 0	0·120	0·120
Lighting	10 0 0	0·080	0·080
Supervision	50 0 0	0·400	0·400
Cost of licences	6 0 0	0·048	0·048
	£1,284 0 0	10·272	8·756

NOTE.—Column 3 is added to show what would be the cost when items for fuel, lubrication, tire repairs and maintenance are reduced by improved design.

TABLE IVB.—WORKING-COST OF MOTOR-OMNIBUSES IN THE COUNTRY IN SEPTEMBER, 1906.

Average daily mileage 80
Number of days worked per annum . . . 200
Average annual mileage 16,000

	Per Annum.	Per Mile.
	£ s. d.	Pence.
Wages, drivers at 40s. per week . . . }	143 0 0	2·145
„ conductors at 15s. per week . . . }		
Fuel (6 miles per gallon at 10d.)	111 0 0	1·665
Lubricants (100 miles per gallon at 2s.) . . .	16 0 0	0·240
Tire repairs at 2d. per mile	134 0 0	2·010
Maintenance and repairs	135 0 0	2·025
Depreciation at 20 per cent.	170 0 0	2·550
Insurance (fire and third party)	50 0 0	0·750
Garage	30 0 0	0·450
Cleaning omnibuses (done by conductor)	0 0 0	0·000
Lighting	20 0 0	0·300
Supervision (engineering and traffic)	50 0 0	0·750
Licences	4 0 0	0·060
	£863 0 0	12·945

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TABLE V.—WORKING-COST OF A 5-TON PETROL-DRIVEN MOTOR-WAGON.

Average daily mileage	56
Number of days worked per annum	250
Average annual mileage	14,000

	Per Annum. £	s.	d.	Per Mile. Pence.
Wages	148	0	0	2·52
Fuel	78	0	0	1·33
Lubricants	17	12	0	0·30
Maintenance	105	0	0	1·80
Depreciation at 20 per cent. on £700	140	0	0	2·40
Rent	26	0	0	0·44
Insurance	26	0	0	0·44
Sundries	13	0	0	0·22
Total	£553	12	0	9·47
Cost per net ton-mile, average load 2½ tons	..			3·79

TABLE VI.—WORKING-COST OF A STEAM-DRIVEN MOTOR-WAGON OF THE TYPES ILLUSTRATED IN FIGS. 6 AND 7, PLATE 2, DRAWING ONE TRAILER.

Maximum Load 10 Tons.

Average daily mileage	56
Number of days worked per annum	250
Average annual mileage	14,000

	Per Annum. £	s.	d.	Per Mile. Pence.
Wages	148	0	0	2·52
Fuel (Welsh coal)	29	10	0	0·50
Lubricants	8	16	0	0·15
Maintenance	39	0	0	0·66
Depreciation at 20 per cent.	130	0	0	2·20
Rent of wagon-shed	26	0	0	0·44
Insurance (fire and third party)	26	0	0	0·44
Water and sundries	13	0	0	0·22
Total	£420	6	0	7·13
Cost per mile, average load of 8 tons one way or 4 tons both ways	..			1·78

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TABLE VII.—WORKING-COST OF A 6-TON STEAM-WAGON DRAWING ONE TRAILER.

Maximum Load 10 Tons.

Average daily mileage	50
Number of days worked per annum	275
Average annual mileage	13,750

	Per Annum. £	s.	d.	Per Mile. Pence.
Wages (driver at 40*s.*, lad at 15*s.* per week)	143	0	0	2·50
Fuel (gas-coke 65 tons at 8*s.* per ton)	26	0	0	0·45
Lubricants (48 lbs. grease at 10*d.*; cylinder and lubricating-oil 60 gallons at 1*s.*)	5	0	0	0·09
Maintenance and depreciation	100	0	0	1·74
Rent of wagon-shed	25	0	0	0·44
Insurance (fire and third party)	25	0	0	0·44
Water	3	10	0	0·06
Licence and sundries	5	10	0	0·09
Contingencies	7	0	0	0·12
Total	£340	0	0	5·93
Cost per ton-mile of load, average load of 8 tons one way or 4 tons both ways	..			1·5

TABLE VIII.—WORKING-COST OF A HEAVY TRACTION-ENGINE TRAIN CONSISTING OF ONE TRACTION-ENGINE AND THREE TRAILER-WAGONS.

Average daily mileage	30
Number of days worked per annum	275
Average annual mileage	8,250
„ load. Tons	14·3
„ ton-miles per annum	117,900

	Per Annum. £	s.	d.	Per Mile. Pence.
Wages	163	16	0	4·76
Fuel	127	8	0	3·70
Oil and stores	15	12	0	0·45
Repairs	65	0	0	1·89
Rent	13	0	0	0·37
Insurance	2	12	0	0·07
Licences	15	12	0	0·45
Depreciation at 7½ per cent.	60	0	0	1·74
Washing out boiler	13	0	0	0·37
Establishment charges	24	0	0	0·69
Total	£500	0	0	14·49
Cost per ton-mile	..			1·01

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TABLE IX.—COST OF CONVEYING MARKET-GARDEN PRODUCE TO MARKET STEAM-TRACTORS AND TRAILERS (SEPTEMBER, 1906).

Distance to first market	12 miles.
Average number of journeys to this market per week	12
Distance to second market	5 miles.
Average number of journeys to this market per week	4
Sundry journeys to station	8 miles.
Number of tractors employed	3
,, ,, trailers employed	5
Average load out	6 tons.
,, return load, sometimes manure, sometimes empties	3 ,,
Total annual mileage of three tractors	16,640 mil
Average annual mileage per tractor	5,546 ,

	Average per Tractor per Annum. £	s.	d.	Per Mile d.
Wages	140	0	0	6·058
Fuel (Welsh coal)	40	0	0	1·730
Lubricants	10	0	0	0·432
Maintenance and repairs	25	10	0	1·108
,, of trailers	10	0	0	0·432
Depreciation at 20 per cent. per annum	80	0	0	3·456
,, of trailers at 7½ per cent. per ann	18	15	0	0·811
Insurance (fire, third-party and boiler)	14	0	0	0·605
Water	1	15	0	0·757
	£340	0	0	15·384

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Discussion.

The PRESIDENT, in moving a vote of thanks to the Author for his very interesting Paper, remarked that, like all the Author's other communications to The Institution, it contained an immense amount of information, very usefully digested for the benefit of the members. Personally he had the greater pleasure in moving this vote of thanks, on account of the fact that the Author and himself, nearly 40 years ago, were connected with Mr. R. W. Thomson's road-steamers, the traction-engines of that time, and the first rubber-tired vehicles. The President.

The AUTHOR mentioned that the number of motor-omnibuses in London, which was given in the Paper as 700, had increased in the last 6 weeks to 800, a fact which would give some idea of the rapid development of that kind of vehicle. It was fair to say that the air-resistance question was a debatable one, and he hoped those who thought differently from him, and who considered that the figures he had taken from Dr. S——n's experiments were too high, would put forward their views. The resistance of the air to vehicles driven at high speeds was an interesting question on which little information was obtainable, and now that so much attention had been given to the subject, he hoped more experiments would be made with a view to determine the law of air-resistance. It might be asked why he had devoted so many pages to the road question. He had done that with a purpose. He was one of those who were convinced that the future of motor-vehicles depended very largely on the co-operation of the road-engineer. If the road-engineer did not co-operate with the car- and wagon-designer it would be impossible to attain success, and as the road-engineers of the country were strongly represented in The Institution, he had taken the opportunity to press that point. He had an ulterior object. The feeling throughout the country with regard to the roads was so strong, that the present was an opportune moment for following the English custom of collecting funds privately to enable a large-scale experiment to be carried out, to decide whether dustlessness, noiselessness, and reduced rolling-resistance would not be secured by using something other than water as the binding material of the roads, without any increase in the cost of maintenance, or so small an increase that the total cost to the country—for it had to be borne by the country, whether it was spent on roads or on the repair of vehicles—would be largely reduced. The Author.

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Mr. Beaumont. Mr. W. Worby Beaumont observed that the subject was so wide that the Author might well have filled a whole volume instead of writing a single paper. The broad title "Modern Motor-Vehicles" enabled the Author to include various kinds of traction-engines, which were not usually covered by the term motor-vehicles. They had been modified so much in various ways during the last few years, in order to perform work which was attempted more or less successfully by motor-wagons, that the Author was no doubt correct in bringing them into the Paper. For a good many years petrol and steam vehicles, heavy and light, as well as electrical vehicles, had occupied Mr. Beaumont's attention, and it had needed about 1,200 pages of a book to enable him to cover about three-fourths of the field that the Author had usefully dealt with. In the account of the early work done 70 and more years ago, he thought the Author had not overstated the claim that could properly be put forward on behalf of Englishmen, including Hancock, Gurney, and others, who accomplished so much in connection with motor-vehicle work; and he quite agreed with the Author that the English motor-industry would have been in a much better position than it was now if it had not been for the restrictions imposed, not by mechanical limitations but by limitations which were now looked upon as being without sufficient justification. One thing the Author had omitted to mention in giving credit to those men, namely, the fact that they accomplished what they did without either the materials or the facilities that existed to-day in the way of tools. Mr. Beaumont claimed for them, and for what they accomplished, a great deal more than was usually placed to their credit. With regard to the deductions made from a consideration of what was done about 1830, and as to the present position with regard to vehicles propelled by steam, there was another word to be said. On p. 3 a few remarks were made as to the position in which the industry might have been at the present time, and credit was properly given to two or three, including Daimler and Benz and others; but it should be remembered that again an Englishman, E. Butler, quite as early as those mentioned, made a petrol motor-vehicle, although a small one, with a successful vaporizer. The drawings and designs might be looked at to-day with a great deal of pride. They showed what was achieved in 1884, and that motor-vehicles might have been placed on the English roads but for the fact that there were restrictions, which were only removed after it was seen that they were operating to the advantage of foreigners. With regard to the general arrangements of motor-vehicles, it might be remarked that Mr. Bollée—the father, he believed, of the present Mr. Léon Bollée—who had done

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Mr. Beaumont.

so much in connection with petrol vehicles of various kinds, made a steam-vehicle, which in respect of the engine, the suspension, and the drive generally, was the forerunner of some of the most common arrangements of the present day. As the Author pointed out, there were many features of great interest to the engineer in connection with the development of the steam-vehicle. The Liverpool trials and the results obtained therefrom had been alluded to, but it should not be forgotten that in 1889 trials were made at Richmond by the then young Automobile Club, when prizes were given for two petrol motor-wagons, one carrying 6 tons and the other 2 tons, at exceedingly economical rates. Those two vehicles gave indications of the possibilities of vehicles being built on very similar lines. It was a matter of some interest now to those who had been concerned in those trials to know that motor-vehicles had been made on the same lines—unfortunately, not in England—which were doing the heaviest work ever done by any machinery of any kind, continuously, and in greater numbers than any other kind of vehicle, namely, the motor-omnibuses. It was satisfactory to know that more was being done at home now, and that a large number of petrol motor-omnibuses were of English build. The Author said that the motor-wagons in use showed much greater divergence and originality of design than were exhibited in the private motor-car. Mr. Beaumont thought that if the Author would consider a little more fully the extreme ingenuity, not only in the design but also in the methods of production necessary to follow out the design, in the construction of the better kinds of motor-vehicles of the present day, he would admit that at least equal originality had been shown in respect of them. With regard to electrical vehicles for trade purposes, Mr. Beaumont thought he was warranted in saying that for many such uses the electrical vehicle would occupy a very important position in the future. The cost of working was not always the chief question, for convenience often had a monetary value. The Author gave many useful and interesting figures with regard to the cost of working motor-vehicles, but the conditions under which vehicles were used in different places varied so much that a good deal of care had to be exercised in the application of these figures. He quite agreed with the Author as to the road question. With reference to the Table on p. 24, he thought the Author had somewhere made a mistake when he gave the total average net horse-power of the winning car in the Tourist Trophy Race of 1906 as 13·35 HP. Mr. Beaumont had figures which led him to believe that that power had been very considerably exceeded for the whole or the average time of the running of that vehicle.

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Mr. Clarkson. Mr. T. CLARKSON thought that the Table on p. 37, showing the results of a test on the engine and boiler of a 10-HP. steam-car, were extremely interesting, but might have been stated rather more clearly. "Temperature of fuel," which was given as 510° F., was rather difficult to understand; it would be better if it were stated that that was the vaporizing temperature, the fuel being gasolene. The temperature of the fuel before it was supplied to the generator was probably about 60°. The temperature of the steam was shown to be at the boiler 353° of superheat, and at the engine 285° of superheat. The exhaust temperature, 288°, seemed to be higher than the engine temperature initially. It would probably be better to show the initial temperature on the same scale as the exhaust temperature. The cut-off was stated to be at three-fourths of the stroke, and the very low consumption of fuel and water seemed particularly astonishing in view of that late cut-off.

The Author. The AUTHOR pointed out that the engine was a compound engine, the cut-off being in the first cylinder only.

Mr. Clarkson. Mr. CLARKSON considered that that fact ought to have been stated, because otherwise there appeared to be a drop of 407° by expanding only 33 per cent. The fact of its being a compound engine altered the matter; he thought it would be fair to say the total ratio of expansion was 3 or 4, or whatever it happened to be. He did not think there was the least difficulty in obtaining tests quite equal to that from a steam-engine using highly superheated steam, and the possible limit of economy in that direction had not yet been reached. The employment of mushroom valves had enabled great economy to be effected, and the reduction in leakage had been really extraordinary. He had recently finished an engine in which mushroom valves were used, and the diagrams were the most perfect approximations to anything theoretical that he had ever seen; there was practically no back pressure, and the point of cut-off was quite square and sharp. Although the Author gave only examples which might be regarded as typical, Mr. Clarkson thought more might have been said in regard to the automatic type of steam-generator fitted on many motor-vehicles.

Mr. Henwood. Mr. E. N. HENWOOD did not know whether the Author was acquainted with a set of wheels which were described by some people as "spring-wheels" and which had been used upon one of the "Vanguard" motor-omnibuses very satisfactorily. The weight on the four wheels was cushioned by 800 cubic inches of rubber and 600 cubic inches of rubber in the two back wheels cushioned the drive. One owner had arranged to have seventy motor-omnibuses fitted with these wheels provided the Local Government Board

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Regulations could be modified so as to allow a wooden-tired, resilient wheel to run at 12 miles per hour. He would be glad to hear whether engineers were of opinion that a road would be more injured by a vehicle running at 12 miles per hour than by one running at 8 miles per hour on resilient wheels. Mr. Henwood.

Mr. MERVYN O'GORMAN thought that the subject most prominently brought forward in the Paper was the competition between steam and petrol. The Author had thrown down the gauntlet boldly, and though there were probably many in the room who realized precisely the position, it might not perhaps be so clear to those who had not been associated with the Author, as Mr. O'Gorman had been for many years, on committees dealing with automobile matters. On p. 42 there was a Table in which appeared the item "Private motor-car, petrol-driven, 14·4*d.* per mile," and contrasted with it was another item, "Private motor-car, steam-driven, 7·36*d.* per mile." Both were put forward as typical cars. The annual figures were unimportant, except that to get those annual figures the Author had introduced an important item of depreciation, which he had worked out at "per mile" on pp. 59 and 60, where an analysis of the figures was given. Broadly speaking, £300 a year was perhaps not an excessive figure to pay for the running of a 28–36-HP. motor-car of the type illustrated, nor was £175 an excessive annual figure for the other type of motor-car, which, though it did not exist, might quite well have been put upon the market by the makers of any steam-cars. The point which the Author was attempting to make was an appreciable superiority of the typical steam-car over the typical petrol-car. Mr. O'Gorman had no interest in either type, but he did not think the Paper was quite fair to one of the competitors. To begin with a small point, whereas lubricating oil and grease were charged at 1·1*d.* per mile to the 28–36-HP. petrol-car, lubricating oil and grease were charged at only 0·3*d.* per mile, or about one-fourth, for the steam-car; and yet the temperatures determining the kind and the cost of oil were much the same with engines issuing highly superheated steam and with petrol-engines. The difference between the amount of lubrication of gear was not important; for the wheels it was of course the same, and for the steering, etc., nearly the same. These assumptions were actually contradicted by other Tables in the Paper. The figure for the petrol-car where it came in competition with the steam-car was 1·1*d.* per mile, which amounted to a large sum on 5,000 miles. But turning to p. 62, where a 5-ton petrol-driven motor-wagon of about the same horse-power was mentioned, which would naturally be supposed to use much more lubricant, it was found that the Mr. O'Gorman.

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Mr. O'Gorman. Author estimated the lubricating materials at the rate of only 0·3*d.* per mile, or one-fourth of the rate for the pleasure-car. Mr. O'Gorman suggested that that was due to some misapprehension of the subject, because he believed the Author was, as a matter of fact, more familiar with the steam-engine than with the petrol motor-car. Turning next to depreciation, the comparison of £105 depreciation for a petrol-car and £83 for the steam-car, particularly when expressed as a rate per mile, was also, he thought, prejudiced in more than one way. To begin with, the cost of the petrol-car was taken at £735, the cost of the steam-car at £550, and the cars were put forward as approximately equivalent for all practical purposes. Though a case could be made out by showing that, with care in manipulation, a steam-car was capable of climbing a hill at about the same pace as a petrol-car of greater rating, this by no means established the equality, in view of the difference, not in degree but in kind, of the advantages offered by the two types. Moreover, he did not think it was fair to suppose that the person owning one of the 28–36-HP. petrol-cars would only travel 5,000 miles with it in a year. The mileage which people took out of their cars was very variable, but 5,000 miles did not fairly represent the amount of use to be got out of such a large car. Ordinary electric landaulettes in town use were reckoned by the people who worked them to run about 5,000 miles per annum, although their range was limited to about 25 miles per day. But for the petrol-car which was used—as the large majority of cars were—more or less as a London carriage, doing roughly 25 miles a day about town, and 100 miles out into the country at week-ends, 5,000 miles was quite inadequate. A reasonable annual figure would be more like 10,000 miles, and even if that were obtained at the cost of slightly increasing the amount expended on repairs it would be found that about £300 would cover the out-of-pocket costs of 10,000 miles a year. The Author's remarks on tires also required criticism, because he only allowed 1,200 miles per tire-cover on the back wheels, whereas Mr. O'Gorman could say with assurance that that was much too little, even for the type of car mentioned. It was reasonable to allow 2,000 miles to a back tire-cover under severe conditions, and under the average conditions of the 28–36-HP. car mentioned, the annual expenditure on that particular item should be much less than the Author indicated. From the very cheap tires put on the steam-car it was clear that a much lighter car was in question, although from the weighings of all types of cars at various competitions, steam-cars were not lighter than petrol-cars of equivalent rating and comfort. Mr. Cozens-Hardy would point out some inexactitudes in the fuel-

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consumption estimates, and he only regretted that time precluded his dealing in a similar way with the far more important question of motor-lorries, wagons, and omnibuses. Mr. O'Gorman.

The AUTHOR, before the discussion proceeded further, desired to refer to the death of Mr. Serpollet which had taken place since the reading of the Paper. Those who had read the Paper would notice that the Author's hopes for the future development of steam-power for the driving of cars and commercial vehicles depended greatly on the successful carrying out of the inventions of the deceased engineer. He believed that by his improvements in steam-generating and the use of steam of high temperature Mr. Serpollet had done more for the steam-engineer than any man had done since the death of Mr. P. W. Willans. It had been his good fortune to know Mr. Serpollet very intimately during the last few months when, although already suffering from illness, he was engaged in perfecting very beautiful inventions relating to the generation of steam, inventions which, now that he was dead, would probably fall into less competent hands. Mr. Serpollet was an inventor of the highest type and a thorough engineer to his finger-tips, a man who lived for his art and whom, therefore, it was a pleasure to meet and to talk to. He was the first to conceive the idea that the boiler of a steam-engine might be so reduced in size and weight as to become quite an insignificant piece of apparatus compared with the engine itself. Although Herreshoff and others had gone some distance in the direction of reducing the size and weight of the generator, no one had so thoroughly realized the idea of reducing the generator into the simple form of a small coiled tube intensely heated, through which the water passed on its way to the engine-cylinder, and was flashed into steam. Hence the name, "flash-boiler." Mr. Serpollet had not been without his imitators. White in America had done wonders by following in his footsteps, and others on this side of the Atlantic had done the same; but Mr. Serpollet had remained true to his original idea. One stroke of the feed-pump corresponded with one stroke of the engine, the only energy stored in the generator being that due to its heated tubes. The wonderful results obtained by Mr. Serpollet in obtaining great power at very low weights were well known. Quite recently engines and generators which developed 70 HP. had weighed less than 600 lbs., including the weight of the condenser. At the time of his death Mr. Serpollet was engaged on an invention which would have far-reaching effects, namely, that of obtaining combustion by forcing measured quantities of the combustible into a chamber together with measured quantities of air under pressure, burning The Author.

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The Author. them somewhat in the form of a continuous series of explosions, and in that way getting the theoretical amount of energy out of the fuel. Mr. Serpollet had shown to the Author results far exceeding anything that had yet been obtained in this direction. He believed that Mr. Serpollet's merits as an inventor and engineer were not so well known and appreciated now as they would be a few years hence, when his great work could be seen from a more distant standpoint.

Mr. Inglis. Mr. JAMES C. INGLIS, Vice-President, was inclined to think that the Paper was the first of a series of Papers on the subject which would be read before The Institution. The Great Western Railway Company had had some experience in connection with motor-vehicles, which he would briefly summarize. The company started about the end of 1903 with two cars; to-day they had eighty-four cars running in all parts of the country; and in 1906 those cars carried a million and a half passengers. The company were quite satisfied with the results of the passenger part of the undertaking, but as regarded goods, especially country goods, it had not been quite so successful. He was very glad to see the advice the Author gave on the subject of the construction of roads. The Paper practically showed that roads were now an adjunct of the great railway-systems, and every station was becoming a starting-point for carrying the traffic further. He thought every railway man would agree that as time went on the business of railway-companies—at all events in England—became more and more detailed every year; the parcels making up 1 ton of goods tended to become more and more numerous. The reason was obvious: traders had to carry on their business with less capital, and therefore had to order goods in small quantities; and he believed that that fact would be at the bottom of the success of motor-car working in country districts. With regard to roads, his company had had some strange experiences. He had recently mentioned [1] the case of a road-authority whose surveyor was of opinion that it was better for new road-metal to be gradually worked in by traffic than to be rolled, and who consequently declined to roll the roads, a course which had obliged the company to withdraw the service, as they could not afford to have a set of tires, costing them £127, destroyed in a week by driving the cars over unrolled basalt. The withdrawal of the cars caused something like a revolution in that countryside, which ended in the county council taking over the roads from the sub-contractor; and they were now kept in excellent order. With the exception of

[1] Minutes of Proceedings Inst. C.E., vol. clxv, p. 25.

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turnpike roads and a few main roads, there were many public roads quite unfit to carry motor-traffic, even pleasure traffic. For instance, at Beattock, where the traffic was entirely pleasure-traffic, the cost of the road had risen to three or four times what it was before motor-cars became popular. In another case, which was now under discussion, the Great Western Railway Company had been asked by a local authority to put cars upon a road between Abergavenny and Brecon. They did so and carried the mails, and it became quite a useful cross-country connection about 20 miles in length. The local authority, however, had just become concerned because they found that the maintenance of that road had cost £1,000 more than in the year before the cars were put on. They wanted the company to pay the extra cost, and of course the company had to point out that if such a charge had to be made the service of cars would have to be stopped. The suggestion now was that there should be a tax on all motors, and the Government should take the matter in hand. He knew of no case where his company had put on a road-motor service in which the grumbling had not been loud with regard to dust and other things, but when it was proposed to take the cars off, their convenience was so great that the district could not contemplate any such course being followed. He could give numerous instances of the effect on the value of land in parts where motors passed; within 6 months of starting a service, land which had been in the market for years sold at nearly double its former value. Of course he was not speaking of the road to Brighton, where he believed property had not appreciated. With regard to waterproofing roads, he ventured to think that if the road-surveyors and authorities studied McAdam's book more, they would be able to improve the roads very much. McAdam insisted strongly on the necessity of breaking the stone to a small diameter (about 1½ inch) and was very particular that roads should be made without the assistance of so-called binding material—sand, clay, or road-scrapings. If a road was made with stone rolled several times, with or without the assistance of water, and then a topping of sand was put on, if necessary, and rolled in, it would be found, even with the materials now used, to last a long time. The tarring question was beyond consideration owing to cost. He would also suggest that more attention should be paid to the appointment of surveyors. In the Federated Malay States, where there was a rainfall of upwards of 100 inches per annum, the roads were under the care of properly-trained engineers and were admirable. It was the same in Ireland, where they were in the hands of well-trained men. He submitted that much more could be done by appointing really good men who understood the science of road-making than by using

Mr. Inglis.

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Mr. Inglis. tar, which, excellent as it was, was prohibitive in cost. It might fairly be put down to the credit of the motor-car industry that although his company had carried a million and a half people in 1906, and since the services were first introduced the number of passengers conveyed had been upwards of 3 millions, there had been no serious accident to any of them. The "lame ducks" at the sides of London streets were so common as to give rise to a general impression that when a man entered a motor-bus he was not sure of reaching his destination. But his company found that a passenger could travel on an average 3,332 miles on certain reasonable routes without a single stoppage of more than 8 minutes' duration. He did not think that was at all bad for a beginning. Most of the troubles arose from lubrication, and he had been delighted to see that the great advance made during 1906 had been in that direction. The Great Western Railway Company were fortunate enough to have in command of their new venture an expert like Mr. Coventry, because without a thorough engineer, and one who really went into details, motor-cars were bound to be failures. He believed that the cost of repairs would be reduced, and as regarded depreciation, although at present they were writing off 20 per cent., the figure which the Author took in the Paper, they already believed this would prove too high in the future: for with the company's earliest motor-omnibuses, which were the first to be put on the roads in England, 12½ to 15 per cent. was at present found sufficient to cover this charge. That, of course, was exclusive of the cost of tires, for which the best result obtained so far was 1·22*d.* per car-mile. The average had already been reduced to 2*d.* per mile, whereas at the beginning it had been 3½*d.* It might therefore be fairly argued that a considerable improvement would take place in the next 3 or 4 years. There was a little difference between the company's figures and the figures given in the Paper with regard to country work, and that arose entirely from the difficulty of fitting in the times of the men with the times when people wished to travel. Most of the country services were provided with two drivers and two conductors, because it was necessary to start early in the morning and take the people where they wanted to go, and to bring them back later at night than would be covered by a fair day's work for the men. On that account the cost of labour came out higher than that mentioned in the Paper. Another point was that the figures he had given could not have been arrived at without having a certain proportion of spare cars, which were absolutely necessary when a public service of motor-cars was run. He was very glad to hear that the Author had such a high opinion of the possibilities of steam-cars. The increasing price of petrol was against its use for commercial purposes,

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and the use of a steam-car would enable a less expensive fuel to be utilized. Experience in New York had shown that the electric car was likely to compete strongly with the others, at any rate for parcel work, and his company shared that opinion. They were now arranging for the collection of parcels on a scale which would be impracticable without mechanical traction. Mr. Inglis.

Mr. F. H. J. TRIER described some of the improvements which had been made on the Continent in armouring roads for heavy traffic. Using the old macadam road as a foundation, a little of the surface was removed, the road was given the correct camber—generally much less than at present—and the surface was rolled. Then small cubical or irregular sets, about 4 inches in depth and 3 inches by 3 inches or 4 inches by 4 inches, were placed on the roads, almost like mosaics. They were sorted according to depth, the deeper ones being placed on the crown of the road. Only slight differences in depth of adjacent sets were permitted, so that the amount of sand, in which the sets were bedded and which was used only to adjust differences of level, might be as small as possible. After laying, the sets were rammed until firmly bedded on the foundation. Before and during this process, the road-surface was freely watered and the spaces between the sets were well filled with sharp sand, with which also the road was covered on completion, to be further worked into the joints by the traffic. These sets were often placed in circles, the man sitting at the centre of a circle and paving as far as his arm could reach, gradually approaching the centre; another circle was then set off, and the work proceeded in that way, the idea being to break joint as much as possible. A still more modern method was to place the small sets diagonally; it was simpler, and it obviated the corners, which were difficult to fill. Roads armoured in that way had now been in use for more than 14 years, and some of them in the crowded industrial district of Essen, where they bore the very heavy traffic of coal- and brick-wagons, had shown remarkable results; so much so, that local authorities had voted many million marks for the extension of such roads. Fine roads were to be seen at Wiesbaden and in many other towns. In the heart of the town such roads were laid to the right and left of the tram-lines, larger sets being interposed between the tram-rails and the small sets. These small-set roads were believed by many to have a great future. They were dustless and comparatively noiseless; their life was computed at 30 years, and with a fair amount of attention it might be longer, depending upon the traffic. The cost of laying was not prohibitive. In Westphalia it was between 3*s.* 6*d.* and 4*s.* per square yard, and it was thought that such roads could be Mr. Trier.

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Mr. Trier. armoured in England for between 5*s.* and 6*s.* per yard. Several examples were already to be seen in this country. A trial road had been laid early in 1906 at Stockport, and another fine example was to be seen on the Forest Road, Nottingham. In Liverpool, near Bootle, there was ½ mile of excellent road, and the authorities at Portsmouth dockyard had made trials with such satisfactory results that the paving was to be increased. The Shorts Road at Carshalton was a very narrow road, and had been laid down on 6 months' trial; it had been carrying very heavy traffic, trolleys carrying rails and about 10,000 tons of sets passing over it, and still it was in excellent condition except in one spot, where it had given way in consequence of a hidden drain which had not been properly set. The basis of such roads was their foundation upon the old, strong, macadam road, which was left intact as much as possible. Given that, there could be no doubt of the excellence of the results.

Col. Holden. Colonel H. C. L. HOLDEN, R.A., proposed to confine his remarks to one or two points which he was most interested in and had studied most, the first being the question of air-resistance. The Author had taken, as his factor for determining the power absorbed by air-resistance, a figure obtained by Dr. Stanton from experiments at the National Physical Laboratory,[1] namely, 0·27 lb. per square foot of surface exposed at a speed of 10 miles per hour. That was the same as the ordinary equation $P = 0{\cdot}0027\,AV^2$, where P was pressure in pounds per square foot, V the velocity in miles per hour, and A the exposed area in square feet; but in quoting Dr. Stanton's results the Author had forgotten to add that those results had been obtained on a plate which was flat and very thin, and that on experimenting with other forms Dr. Stanton had found that for a flat-ended cylinder having a length equal to three diameters, the 0·0027 had to be multiplied by something like 0·65 in order to obtain the correct result. That was to say, the resistance of the air to such a flat-ended cylinder was much less than that of a flat thin plate. It could hardly be said that the motor-car was a flat thin plate or even approximated to that form, and therefore there was presumably some factor of reduction that must be applied in order to get the correct result with regard to the horse-power absorbed by air-resistance. Taking the car which was first in the Tourist Trophy race of 1906, and for which figures were given in the Paper, it would be found by applying the Author's coefficient of 0·0027 that at 50 miles per hour that car would absorb 23 HP. for rolling- and air-resistance, and at 55 miles

[1] T. E. Stanton, "On the Resistance of Plane Surfaces in a Uniform Current of Air." Minutes of Proceedings Inst. C.E., vol. clvi (1904), p. 78.

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per hour the power absorbed would be nearly 30 HP.; that was the power that had to be exerted by the engine at the road-wheels, not the brake horse-power of the engine. It was known that that figure was far too high for the power of the engine of that car. He could give an example taken from the Tourist Trophy race up Snaefell, on a mountain road which had a gradient of about 1 in 10. It was known from the times the car had taken to climb this hill that the power exerted at the road-wheels had been just 24 HP., corresponding to 26 miles per hour, and that on the downward slope of the hill the car must have been travelling at 60 miles per hour or more in order to maintain the mean speed of 39·29 miles per hour. His own calculations, based on results with motor-cars at high speed, showed that the coefficient was 0·0017 instead of 0·0027, and if that figure was applied to cars running at high speed on the level or ascending a steep hill, it would be found to yield very nearly the correct power. Turning again to the Table in the Paper he would call the Author's attention to what appeared to be a slip. He had said that the winning car was going uphill at as low a speed as 26 miles per hour, and on the other side of the hill it was probably going at more than 60 miles; in the rest of the course it might have been running at anything between 40 miles and 50 miles per hour. But the Author had taken the air-resistance at the average speed. If he worked that out and took the speeds that that car attained on the road, he would find—apart from the principle involved, namely, that the mean of the squares was not the same as the mean of the plain numbers—that his figures were entirely wrong and that they ought to be much higher. That of itself pointed to the fact that 0·0027 was too high; but of course it also upset the important figure at the bottom of the Table—the petrol used per net horse-power-hour, which was given as 0·83 lb., which was 0·747 pint. That was not the brake horse-power, but the horse-power at the road-wheels. Taking the Author's figure of 75 per cent. efficiency, the corrected result would be 0·56 pint of petrol per brake horse-power-hour. He hoped that would be obtained some day, but it had not been obtained yet, nor anything like it under similar conditions. The Author gave an estimate of the cost of running a petrol-car and a steam-car for a year. It so happened that quite recently, a well-known motorist had given the actual figures for the year's running of two cars, such as the Author had described, one of them being a 30–40-HP. Daimler as against the 28–30 HP. of the Author's example, and the other an 18-HP. White car as against the Author's 20-HP. example. The figure arrived at by the Author, leaving out depreciation—Colonel Holden left that out of both calculations as

Col. Holden.

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Col. Holden. it was different in the two, and obviously did not really come into the question of the running-cost of the car—was a total of 12·72*d.* per mile for the two cars. He was obliged to take the two cars because the figures, which were given in *The Autocar*,[1] did not separate them. The figures in *The Autocar* for the items the Author took came out at 4·734*d.* per mile, and according to that the Author's estimate was 270 per cent. too high. Most people knew it was excessive, but Colonel Holden had not been prepared to find it was 270 per cent. too high.

The Author. The AUTHOR pointed out that the estimates were not his own, but those of the Daimler Company.

Col. Holden. Colonel HOLDEN was taking the figures as they stood in the Paper.

The President. The PRESIDENT asked whether Colonel Holden could give the writer's name.

Col. Holden. Colonel HOLDEN did not like to give the name because the writer had only signed his initial "R." He held no brief either for the petrol-car or the steam-car, but he was much interested in the heavy steam-car, and had been disappointed to learn from the recent French trials of heavy vehicles that three steam-cars consumed no less than twice as much fuel per ton-mile as the average of the petrol-cars, and three times as much fuel per ton-mile as one of the petrol-cars. Anyone who desired to see steam in competition with petrol on the same fuel basis would be much disappointed with that result, especially as it had been obtained with the most modern steam-car, the Darracq-Serpollet.

Mr. Swinton. Mr. A. A. CAMPBELL SWINTON desired to give a few statistics, in connection with one particular branch of the subject, which he thought would support Colonel Crompton's views. He happened to be connected with the motor-omnibus industry of London, and at the present moment in London there were over 800 motor-omnibuses, carrying on an average more than half a million passengers per day, or about 200 millions per annum, and taking about £1,000,000 in fares. According to the latest statement by Mr. T. McKinnon Wood, the Chairman of one of the Committees of the London County Council, the Council's tramways were carrying only 180 million passengers per annum. On those tramways £5,000,000 had been expended, while the 800 motor-omnibuses had been put on the road at an expenditure of less than £1,000,000. Therefore the motor-omnibus companies of London were carrying more passengers than the tramways with less than one-fifth of the capital expenditure. He ventured to suggest that before the London County Council embarked upon the expenditure of the further

[1] *The Autocar*, vol. xviii (1907), p. 129.

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£5,000,000 that they proposed, they should seriously take into account whether the same result could not be obtained with much less expenditure by means of motor-omnibuses, and whether a portion of the saving could not be used for the improvement of the streets to enable motor-omnibuses and all other vehicles to run more smoothly and less noisily—a result which was much to be desired. The Author also gave some interesting figures with regard to costs. His figure for the cost of running motor-omnibuses in London was a fair one. Mr. Swinton would not say more because, owing to competition, it was necessary to be circumspect. With regard to motor-omnibuses in the country, however, he was in a happier position. He happened to be a director of the Bath Tramways, which ran motor-omnibuses without competition. In his opinion the Author's figure for running motor-omnibuses in the country was too high. It was practically 13*d.* per mile; while at Bath twelve motor-omnibuses had been working in conjunction with tramways, the omnibuses running 20 miles into the country over very hilly roads, under severe conditions, and in 1906 the costs, excluding depreciation and supervision, came out at 8·56*d.* per mile. Deducting the 2·55*d.* the Author had allowed for depreciation and the 0·75*d.* he had allowed for supervision, the Author's result on a similar basis was 9·645*d.* Therefore, judging by the results obtained at Bath, the Author's figure was about 1*d.* per mile too high. The Author also alluded to road-locomotives dragging a number of wagons, and about a week ago Mr. Swinton had witnessed in Paris an exhibition of the Renard train. He understood that a Renard train had arrived in London, and therefore engineers would have an opportunity of seeing it. The Renard train was invented some years ago by the late Colonel Renard, who died shortly after its invention; but since then it had been much improved. First there was a locomotive or truck carrying an engine, and behind were as many vehicles as the user chose to put. They were all six-wheeled vehicles, the middle pair of wheels on each being driven by a Cardan shaft which ran the whole length of the train, with Hooke joints between the vehicles. The back pair of wheels of each vehicle was loose, but the front two pairs of wheels were steered by the vehicle in front. Wherever the engine was steered, each carriage in its proper turn steered exactly the same course, the wheel-tracks being not more than 1½ inch out. The wheels were so arranged on levers that each pair of wheels always carried the same weight, despite the irregularities of the road. When he first saw the train it was coiled up in a sort of S form in a garage, but it was taken out of the garage and round a sharp corner without the slightest difficulty. A considerable journey

Mr. Swinton.

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Mr. Swinton. was made with very sharp turns. On the return the train was run backwards into the garage, and to do that a boy put a crowbar into a hole in the back wheel steering-gear and led the train into the garage and back into the S form, exactly as though he were leading a living animal.

Mr. Clerk. Mr. DUGALD CLERK congratulated the Author on presenting The Institution with a valuable and interesting Paper on a subject which in the future would probably produce many other Papers. The communication opened up so many interesting points that it was necessary to confine remarks to a few of them. He was in agreement with the Author in the main in his views as to the future of motor-vehicles and as to the necessity for improving the roads; and he also agreed in considering that such vehicles were of enormous importance to the country. In his initial statement the Author had, Mr. Clerk thought, rather understated than overstated when he mentioned 10,000 commercial vehicles. He himself believed he understated when he said that there were 50,000 pleasure vehicles in this country and probably 60,000 in America, and the majority of those vehicles were using the internal-combustion motor in the form of a petrol-engine. The Author had a very strong leaning towards the steam-engine, and no doubt the recent development of the steam-engine had, to a large extent, justified that leaning. One of the most interesting features of the last 20 years had been the astonishing way in which the steam-engine had answered to pressure put upon it by competition. As the gas-engine and internal-combustion engines generally had improved, steam-engineers had applied themselves to introducing further improvements and rivalling gas-engine economy. But, notwithstanding the Author's figures, steam-engine designers had not yet succeeded in rivalling gas-engine economy substantially, although they had greatly improved the economies of the steam-engine. He did not say it was impossible; in fact, he agreed with the Author that theoretically, with a high degree of superheat, it was possible to convert the steam-engine practically into a gas-engine. The amount of heat utilized for the temperature-range of the gas-engine was not the heat which would be utilized from the temperature of the explosion, say 1,700 C. or 1,800 C. down to the temperature of the charge, but was the heat-utilization of the temperature-range due to compression. That was the controlling factor. The consequence was that if steam was heated sufficiently highly it would be possible to make an engine of Brayton type and theoretically to obtain an engine which for a given pressure had practically the same economy as a gas-engine. That would require further deviation from the usual steam-engine lines. It would be impos-

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sible, for instance, to make a piston so short as had been shown in some of the lantern-slides exhibited. It would be necessary to have very long air-cooled pistons and water-cooled cylinders, and generally to adopt the precautions not of the steam-engine, but of the gas-engine. With such an engine no doubt economies could be obtained closely rivalling the performance of the gas-engine, and that was why considerable economies had been obtained by high superheat; by highly superheating steam the steam-engine cycle was being left, and the gas-engine cycle approached. On the question of the actual performance of the engines, he agreed with Colonel Holden that the Author had under-estimated the efficiency of petrol-engines. A first-class petrol-engine tested on the brake in the works would give as the best result to-day about 1 B.HP.-hour on 0·08 gallon, or 0·57 lb., of petrol. Taking the usual efficiency of petrol-engines, 1 I.HP.-hour would be given on 0·46 lb. Therefore, the actual power of an engine as tested by brake in the shop, with the petrol-consumption measured, was about half the Author's figure. That should be compared with the test given by the Author for the White steam-car, which was remarkable. To get 1 I.HP.-hour by steam on 0·975 lb. of gasolene, which was practically petrol, was an exceedingly fine performance, which could not possibly have been obtained without high superheating, as the Author had said. It would be noticed that that figure had been obtained not by a rough estimate of the power used by the engine on the road, but by a brake-test in the shops, and that of course was the fair figure to take in comparing with the gas- and petrol-engine. It would not do to make the two tests on different bases. In the present case the test of the petrol-engine had been made on the basis of an estimate including wind-resistance, a very debatable point. The Automobile Club Committee had been trying to determine what the air-resistance really was, and to obtain a true coefficient. He thought they had obtained a very fair figure through Colonel Holden's work, but that figure was much lower than the one given by the Author, and rightly so, for some complicated reasons that he need not go into. The consequence was that a rough estimate obtained in that way for the petrol-engine should not be taken with the accurate determination obtained for the steam-engine. If they were compared, they ought to be compared on the same basis of a practical test in the shop, where everything could be measured accurately. On that basis it would be found that a good modern petrol-engine consumed less than half the amount required by the steam-engine. It was an excellent performance for a steam-engine to have such a thermal efficiency, and no doubt other

Mr. Clerk.

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Mr. Clerk. improvements would be made and further economies be obtained. The Author claimed many advantages for the steam-car. No doubt a steam-engine was more flexible in a sense, although not in every sense. It was flexible in that a steam-boiler gave a constant pressure, and that pressure could be kept longer on the stroke, and the power of steam-generation was not crippled on coming to a hill. In a petrol-engine the power varied as the revolutions, and therefore it was necessary to have a very heavy maximum torque. But the Author stated that a steam-car could do without any change-speed gear such as was used in the ordinary motor-car. When Mr. Clerk was one of the judges of the 1901 trials there were some steam-cars without gearing, but he understood that most modern steam-cars had gearing, and the recent White steam-car had what was called an emergency-gear; the engine could be allowed to run free by shifting the gear, as in the case of a petrol-engine, or it could be engaged in the ordinary gear, which was three to one, or in the low gear, which was seven to one. So that the White steam-car, at any rate, used gear in addition to the flexibility given by the form of the motor. With regard to the cost of motor-cars, he had for many years driven a motor-car for his own use, and the one he was driving at present—a four-cylinder 18-HP. Siddeley landaulette—he had had for about 3 years. That car had travelled many thousand miles, and his experience with it led him to think that the Author had over-estimated the expense of such cars. It was quite true that if the Author's figures on p. 60 were taken, with the amount allowed for depreciation, and running only 5,000 miles a year, the figures were fairly accurate. Mr. Clerk's car, allowing for depreciation, cost him just about £300 a year, but he drove it many more miles than the Author had assumed, and he thought it would be found that most motorists ran their cars more than 5,000 miles a year. The petrol-consumption in the estimate seemed somewhat high. The car had a rather more powerful engine than his own car, though the latter gave about 22 HP. In a trip to Scotland at the end of 1905 he went from London to Aberdeen through the Highlands for about 2 months, and kept a note of the number of miles run each day. In 3 months the car ran 1,740 miles, consuming 105 gallons of petrol, 7·8 gallons of lubricating oil, and 19 lbs. of grease. The total cost at the price he was paying for those three items was £9 18*s.*, or 1¼*d.* per mile for the first and second items of the Author's estimate on p. 59. The particular car there mentioned required 2·3*d.* In that year he happened to take the number of miles run, and he found that it was rather over 7,500 miles. He knew of many motor-cars running 15,000 miles per

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annum. It seemed to him possible to bring out the cost per mile at anything that might be desired, depending entirely on the views held with regard to depreciation. Many who had motor-cars desired to have a six-cylinder car, and he himself felt inclined to buy one next year; but if he did so it would be hardly fair to mark down his present car at a certain cost; it would not be fair for him to say that he could only get a certain amount for the car because the car had depreciated to a certain extent. If he were content to go on with his present car it would be quite as good 10 years hence. Therefore, taking off the depreciation item, a very large sum had to be deducted at once. The Author had stated that worm-gear had only recently appeared. Colonel Holden and himself were judges in the Richmond Show in 1899, when Mr. Lanchester produced his worm-gear, which was successful and in advance of all the others. Mr. Clerk.

Mr. H. T. WAKELAM, referring to the Author's suggestion that road-engineers should co-operate with the motor-car industry, remarked that so far as he knew the views of English road-engineers, he was quite sure they were willing to co-operate with the Author and any Association that might be formed to bring about some improvement in connection with the roads, if it could be done at a reasonable cost. The Author had referred to experiments that were being carried out privately by several associations, and Mr. Wakelam would like to add that other people were also carrying out experiments at the public expense. All the experiments were being watched very carefully. It was said in the Paper that dustless roads would be of great benefit to the public and save much money; but so far as Mr. Wakelam's experience went in connection with so-called dustless roads, he was afraid they were not going to result in any great saving to the public. He was now awaiting the results of the larger experiments on dustless roads that were about to be undertaken, and he was hoping to be able to put his knowledge at the disposal of the Committee. The Author said that the whole of the improvements up to the present time had been confined to vehicles; but that was not so. In Middlesex in 1889 the main roads cost £49,000 per annum to maintain; in 1905 the same roads cost £90,391. In the period January, 1904, to March, 1906, improvements on the roads alone cost £86,536. Subsidized roads, which in 1890 cost £3,832, now cost £12,500. The main roads of England and Wales in 1901 cost £2,120,332; in 1902, £2,261,919; in 1903, £2,366,163; in 1904, £2,406,754; and in 1905 £2,478,481. Those figures were taken from the official documents supplied by the Local Government Board. The subsidized roads of England and Wales, which were roads that had been created since the county councils came into Mr. Wakelam.

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Mr. Wakelam

operation, were now costing £129,504 per annum, which was in excess of any cost charged by the Local Government Board to the upkeep of main roads. During the period 1901–5 the mileage of main roads increased from 26,986 to 27,380, and the cost per mile from £78 to £90. That showed that since the creation of county councils there had been an increase of more than £1,000,000 in the annual roads-bill of the country. During the last 10 years steam-rollers had increased numerically 60 per cent. over the previous 10 years. In Middlesex alone, during the last 3 or 4 years, on main roads, about 80 acres of wood paving had been laid; and the scavenging of the main roads, which in 1900 cost 4½*d.* per square yard per annum, was now costing 6*d.* On that basis, more than £1,000,000 would be added to the annual cost of main roads throughout England and Wales. During the last 3 years, in connection with tramways and light railways, Middlesex had spent £618,340 on road-widenings, which constituted improvements. From the figures he had given it would be gleaned that something had been done towards the improvement of main roads by the authorities, and that the improvements had not been altogether on the side of the manufacturers of motor-cars and tractors. The Author's diagram showing a 24-foot road with 12 inches camber meant a transverse gradient of 1 in 12. No engineer would think of putting in a camber such as that. The camber of B in *Figs. 11* (1 in 36) was approximately the one principally adopted by all trained engineers. The single-rise road looked as if it would be of great practical utility, but he was afraid the Author had not considered the trouble and annoyance that would be caused to foot-passengers on the lower side of that road. During the winter months the road-sweepings, all swept to that side, would necessarily be in a sloppy state, and he hesitated to think what pedestrians on that side of the road would say when fast motor-traffic ran through the sweepings. Depreciation of property on that side of the road would occur; there would be great difficulty in laying tramways along a road on a slope such as was shown, and considerable difficulty would also arise in connection with converging side roads. Mr. Inglis had referred to the size of the material put on the roads in the days of McAdam. There was a good deal to be said in favour of small-sized material, but, comparing the traffic on the roads in the days of McAdam and the traffic of to-day, Mr. Wakelam did not think that small-sized material would carry the weights that now passed over the roads. Another trouble was that nowadays the stone put on to the roads was broken chiefly by machinery. It was impossible to get the hand-labour available in the days of McAdam, and the machine-

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broken metal was badly fractured and flaky, and therefore would not withstand the same traffic as hand-broken material. Some years ago, as county surveyor of one of the West Midland counties, he had charge of about 500 miles of main roads. He had trial-holes sunk in these roads about every ¼ mile, and he found that the thickness of foundation did not average more than 3 inches, or at the most 3½ inches, of road-material, and for many miles that material lay simply on a clay formation. In Middlesex, within the last 2 or 3 years, it had been necessary, for the construction of light railways and tramways, to excavate in places as much as 3 feet, and sometimes 4 feet, before a foundation was secured fit to carry traffic of that character. On the Great North Road, the Edgware Road, the Bath Road, and the Staines Road, similar conditions prevailed, except in the south-western part, where there was a gravel subsoil instead of the very plastic clay of North and North-West Middlesex. The character of the foundations lay at the root of the question of the cost of maintenance. The climate had a great effect upon roads, and a great deal of the trouble in connection with roads was due to a wet climate and the poor material used by some of the local authorities. If the Association the Author referred to were to send a circular-letter to the 1,850 existing road-authorities asking them to desist from the use of such material as gravel, limestone, etc., and to use only basalts and granites, a great improvement would quickly follow in the district roads of the country, of which there were about 45,000 miles in England and Wales. He was quite at one with the advocates of tar-macadam roads; but his experience showed that, unless such roads were made of something quite different from the materials used hitherto, especially slag, they were not likely to solve the difficulty. Tar-slag had been used in this country for more than 20 years, and Mr. Hooley's device was, he thought, in connection with the mixing of tar-slag, not in connection with the material. About 18 months ago Mr. Wakelam had a large quantity of tar-slag laid, and pressing requests had been received from the local authority to have it taken away again, because it was found to be slippery, and altogether unsatisfactory. In another part of the county some tar-macadam had been laid down on a road which carried heavy market-gardening traffic nightly into London. There was a tramway in the centre of the road, and the side of the road which carried the heavy traffic had gone to pieces in about 14 months: the other side of the road, carrying the unladen vehicles going out of London, was wearing a little better, but already extensive repairs to it had had to be carried out. He did not think tar-macadam would withstand heavy traffic. Tar-slag cost about 3*s.* 6*d.* per square yard to lay.

Mr. Wakelam.

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Mr. Wakelam. The same road in basaltic macadam cost about 9*d.* per square yard per annum: which showed that tar-slag was much the more costly material for the upkeep of that road. As to the possible improvements in connection with the shape of cars, in the last 4 years he had experimented with many cars at various speeds, and had watched carefully the behaviour of different designs; and he had no doubt that, if they concentrated their attention on the subject, makers could effect very considerable improvements. He did not know whether the Author's attention had been called to what was described as an "equalizer," but from what Mr. Wakelam had seen of "equalizers" in connection with light road-cars, he thought the subject was certainly worth the attention of designers and makers of the light motor-cars now used. Any large system of improvements of the roads necessarily affected the ratepayers of the agricultural counties, who, with decreasing rateable values, were in a poor position to bear the extra expense. In his opinion, the only real solution would be for the Government to take up the question of subsidizing the authorities who had charge of roads, both main and subsidized; and he was quite sure that the members of The Institution who had the control of roads would be quite able to carry out the necessary improvements. He did not wish to see any hindrance placed in the way of motor-traffic or the motor-vehicle industry. Given fair play, he was quite sure that the engineers who had control of the roads were quite able and would be very willing to co-operate with the Author and his friends. He added some particulars of the working-cost of a four-cylinder motor-car, 18–22 HP., which he used, for comparison with the Author's figures (p. 59), which, omitting wages, uniform, insurance and licences, worked out at 14·40*d.* per mile. Mr. Wakelam's figures under the same heads were:—

	£	*s.*	*d.*	Per Mile.
Fuel:—Petrol, 13·08 miles per gallon, 6,361 miles in 6 months, 486 gallons .	27	16	4	1·05
Stores:—Lubricating oil, grease, accumulators, accessories and sundry expenses	19	19	8	0·75
Tire replacements and repairs:—Two inner tubes and one rear-wheel cover . . .	17	4	3	0·67
Other repairs, including annual overhaul (half cost)	34	0	0	1·28
Depreciation at 15 per cent. per annum .	48	15	0	1·84
	£147	15	3	5·59

If wages, uniform, insurance, licences, etc., were included, the following had to be added:—

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	£	s.	d.	Per Mile.
Total as above	147	15	3	5·59
Driver's wages	49	17	6	1·88
Driver's uniform (half cost)	7	10	0	0·28
Insurance, licences, etc. (half cost) . .	16	7	0	0·60
	£221	9	9	8·35

Dr. H. S. HELE-SHAW remarked that the fuel question was a subject of great importance. So long as petrol internal-combustion motors were used entirely for the purpose of pleasure, the subject had not been of great moment; but the internal-combustion engine had steadily asserted itself more and more for commercial purposes, and therefore to-day it was a vital matter in connection with road-locomotion to have fuel at a reasonable price. Although it was true that the American production of oil was much the largest, a remarkable change had been taking place in recent years. For instance, in 1904 there were imported from the United States 6 million gallons as against 4½ million from the East Indies; in 1905, 10½ million gallons from the United States as against 8 million from the East Indies; and in 1906, 8 million gallons from the United States as against 13 million from the East Indies, as well as 2½ million gallons from Borneo. Roughly, the percentages imported from the United States were, in 1904, 50 per cent.; in 1905, 56 per cent.; and in 1906, 30 per cent.; whereas the percentages from the new sources of supply had risen from 37 per cent. in 1904 to 42 per cent. in 1905, and 61½ per cent. in 1906, which, with 9 per cent. from Borneo, made 70 per cent. from the East Indies imported into this country in that year. Those figures were taken from a lengthy statement made by Mr. Duckham before the Motor Union Fuels Committee; and he quoted them to show that new sources of supply were being opened up, and no doubt in time Russia would help largely in meeting the increasing demand. It was important to note that at present the two sources of supply were largely in the hands of two companies, the Asiatic Petroleum Company and the Anglo-American Oil Company. He believed those companies were supposed to be competitors, and that there was in no sense a "ring" in connection with petrol; but of course they could not be expected to take the public into their confidence in the matter of any working agreement they might have in regard to price. He was glad to hear that naphtha, in Scotland at any rate, was being largely used. Although it could not be used in England owing to the cost of transport, in Scotland 40-gallon barrels could be obtained at 4½*d.* per gallon, which was less than one-half, and not much more than one-third, of the cost of petrol. According to high authorities, naphtha, which

Dr. Hele-Shaw.

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Dr. Hele-Shaw. was produced from shale-oil, was very satisfactory. Further, 4 to 8 million gallons of benzole were produced in this country in the making of coal-gas, and might well be employed. It was necessary to wash it to remove the odour, but there was excellent authority for believing that, after being washed, it could be satisfactorily used for motor-cars. The production could be increased, if there were a demand, to 10 million gallons per annum. Benzole was now used mostly for commercial purposes. The use of alcohol was a much-disputed subject. Some people thought that it was out of the question, while many others took the opposite view. At present one of the great difficulties was denaturing; but if a method of denaturing satisfactory to the revenue-officers could be discovered, the cost of alcohol would be much lowered, and engines would be designed to use it. If any member had any information on that subject, or with regard to any other fuel, he would do well to place it at the disposal of the Motor Union Fuels Committee. With regard to skidding, the palliatives the Author had mentioned had been tried lately, by the Automobile Club Committee, and the results had emphasized the great difficulty of the subject. Out of forty contrivances very few had survived the initial test, but it was hoped that two or three of those that had survived would turn out satisfactorily in the long-distance trials. A simple non-skidding device which he had seen used with the greatest effect in Victoria Street was the use of the hose. That would immediately remove all danger of skidding, not only for the time being, but practically for the rest of the day. Even if the passengers were not deserving of much consideration the driver was. As the Author said, the drivers exhibited great skill and nerve, and if only for their sake, Dr. Hele-Shaw pleaded with the authorities to use the hose-pipe a little oftener. With regard to the subject of road-resistance the Author mentioned his name in connection with the British Association appliances for measurements of this kind, and stated that up to the present not much progress had been made. When he went abroad, the apparatus for testing road-resistance was left in the hands of a certain gentleman—he would not say who that gentleman was. The real truth was that though it was possible, by using a wheel trailed behind a motor-vehicle, to get excellent results at low velocities, the appliance in question, which was an instrument of this type, had given such discrepant results at high velocities that he was inclined to agree with the Author, who thought that the only possible way was to use an electrically-driven vehicle driving on each wheel, and obtain an autographic record. The Author alluded to the subject of the spring-wheel and its army

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of inventors, but he did not mention the great difficulty those inventors had to meet. Most of the inventions really reverted to the "crustacean" form, with a hard outside and a soft inside, from the "vertebrate," which latter was higher in the scale of creation. The spring-wheel with a rigid rim was of the former type, and had lost the resistance of the spokes, which were the great source of strength. He could not quite agree with the Author in the view he took as to the reason why convex obstacles were more objectionable than concave; he could not believe that a vehicle on meeting a convex obstacle was retarded, and was correspondingly increased in velocity when it met a concave surface. The velocity of the wheel itself might be altered, but surely that of the whole vehicle was not altered, if it had any springs. He congratulated the Author on the last few words of the Paper, in which he said he had not attempted to deal with pedrails or walking machines along with all the other subjects which had been included by him. Invention in that direction had gone much farther than many people were aware of, and the chief inventor, Mr. Diplock, had courageously stuck to the great problem, namely, the necessity, which every word of Mr. Wakelam's had driven home, of getting machines that would not destroy the roads at high speeds. A heavy load could be carried at a low speed or a light load at a high speed, but not a heavy load at a high speed on any wheel that could be made at present. He congratulated the Author also on his courage in saying that much might be obtained from such inventions, and he hoped the Author would live to see some remarkable developments in that direction. Dr. Hele-Shaw.

Dr. A. W. BRIGHTMORE observed that probably many engineers besides himself had been struck by the fact that the advent of motor-traffic had reversed the previously accepted notion that a vehicle should be pulled instead of pushed. The reason for that reversal was contained in the Author's statement that the ordinary steering-lock and turn-table used by earlier vehicles and traction-engines were not suitable for high speeds, and a space had to be allowed for the front wheels to pass underneath the body. That of course was a very valid objection in the case of light pleasure vehicles, but in the case of heavy vehicles, such as motor-omnibuses, if it could be proved that there was any advantage in front driving, it would be only a question of design to utilize it. He did not contend there was any mechanical advantage in the mere fact of pulling as opposed to pushing, but it had appeared to him, when he first considered the subject, that front driving lent itself to a more scientific method of articulation of the vehicle, by which he meant Dr. Brightmore.

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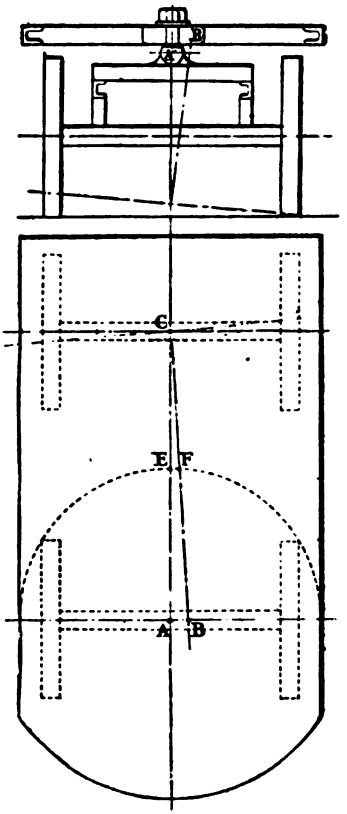
Dr. Brightmore.

that the fore part of the vehicle could be connected to the body in such a way that the weight on each wheel remained constant, however uneven the road might be, which prevented any twisting of the main frame or of that of the fore carriage. Of course, if the springs were relied upon to adapt the vehicle to an uneven road, the uneven pressure on the springs necessarily introduced strains in the main frame which were constantly varying in magnitude, and therefore caused vibration in heavy vehicles. He had been so much impressed with the question that he decided to make some experiments on front driving, and for that purpose he had a vehicle built in which the front wheels were the driving wheels. The vehicle proved to have certain defects, but nevertheless it enabled him to obtain data which were necessary to work out the essential features of the problem. He had placed a diagram on the wall (*Figs. 15*) which showed the principle on which that experimental vehicle was constructed. The elevation in *Figs. 15* showed the fore-carriage of the vehicle; above the front axle there was fixed at A a socket in which rested a ball attached to the frame. The back of the fore-carriage was held up, so as to maintain the fore-carriage parallel with the frame lengthwise, by means of a slider which could turn on a horizontal pivot at the back of the fore-carriage, on the same level as the ball; the slider worked in a circular segment which was attached to the body. By that means a wheel was able to go over an obstacle without causing any strain on the main frame or fore-carriage. In that vehicle the only method of steering he saw at the time was by the use of brakes, but the conclusions he had come to from extended experience were that brake-steering failed under certain conditions,

Figs. 15.



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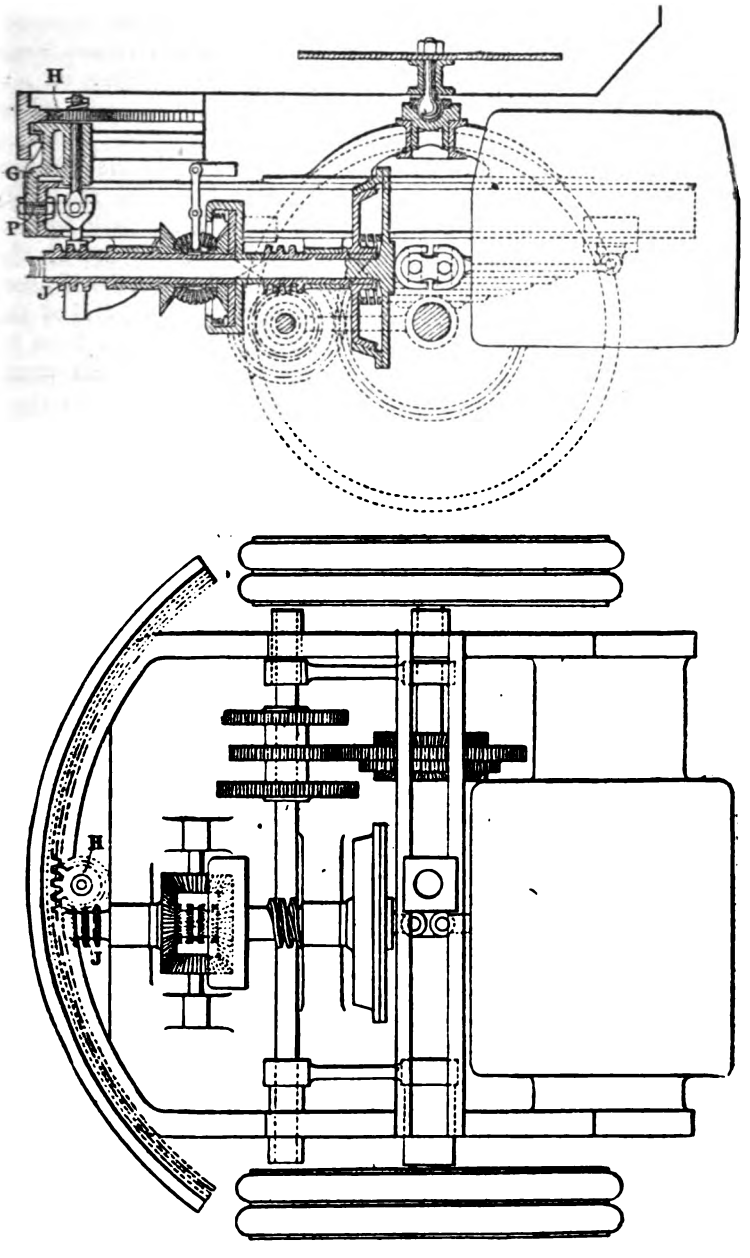
Figs. 16.

Dr. Brightmore.



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Dr. Brightmore.

and that it was necessary, in front driving, that the back of the fore-carriage should be always mechanically connected with the body. The difficulty of connecting the back of the fore-carriage to the body consisted in the fact that the slider working on the segment tended to move relative to the segment whenever one wheel mounted an obstacle or another fell into a depression. *Figs. 15* showed that when a front wheel mounted an obstacle the ball was drawn over a certain distance A B, and that turned the body of the vehicle about the centre point C between the back wheels, and consequently a point E on the body at the distance of the circular segment would move a distance E F smaller than the distance A B moved by the ball, in the proportion of the distance C E of the segment from the back axle to the distance A C of the ball from it; but a point on the fore-carriage at the level of the ball would move over the same distance as the ball. Thus when the front wheel mounted an obstacle there was a relative motion between the slider and the circular slide. It occurred to him that difficulty might be got over if, instead of pinning the slider to the fore-carriage at the level of the ball, it were connected at a lower level. If the pin P (*Figs. 16*), connecting the fore-carriage with the slider was riveted at a height which bore the same proportion to the height of the ball that the distance of the segment from the back axle bore to the distance apart of the two axles, then it would be seen that a point on the fore-carriage at that level would move the same distance as a point at the same level on the body when the front wheel mounted an obstacle, and consequently the effect was simply a slight rotation of the fore-carriage relative to the body. This point P might therefore be termed the "neutral point." By mounting the mechanism for turning the fore-carriage on the slider G, it was possible to rotate the fore-carriage by means of that mechanism. The drawings showed a spur-wheel working on the toothed segment rotated by a worm J and worm-wheel, thrown into gear with the motor when the turning of the fore-carriage, for steering purposes, was desired. This showed that a recognition of the "neutral point" made front driving mechanically possible, whilst allowing the axles absolute freedom to move relatively to each other in vertical planes, which, he thought, might be a matter of some importance.

Mr. Leader.

Mr. H. LEADER mentioned that front driving had already been worked out, perhaps in a more mechanical way than in the scheme just described, by a North London firm of steam-wagon builders. They built not long ago a machine which was intended to carry the bodies of old omnibuses, the assumption being that the bodies of the present horse-propelled omnibuses were of some use and might

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be fitted to a chassis consisting only of a frame and front wheels. The radical defect of the design was that, in order to obtain a spring in the front part of the machine, helical springs were used instead of laminated springs. He believed an omnibus of the kind was running still, the only one that had been built. But for that defect, it might have been a very serviceable machine. He could not follow the last speaker as to why the front wheels should not be steered in the ordinary way without brake-steering being resorted to. With the machine he had mentioned the front wheels were actuated by ordinary mechanism. The wagon built by the firm had also a rocking motion for the front carriage, which, however, did not in the least affect the connection between the body and the fore-carriage, as the rocking motion was entirely self-contained. The front pair of driving-wheels were carried in a self-contained rocking bogie on a pair of horizontal, longitudinal pins, and the whole thing could mount any obstacle or twist sideways without in the least interfering with the body. He believed the assumption in building the engine had been that front driving would materially lessen the tendency to skid; but whether that had actually proved to be the case or not he was unable to say.

Mr. Leader.

Mr. F. J. Wood observed that in the first words of his Paper the Author voiced the general opinion with regard to the introduction of motor-vehicles. The generally accepted meaning of the word "invasion" was, Mr. Wood believed, a trespass on the rights of another. That motor-vehicles had come to stay no one could gainsay, and he thought it was the duty of everybody to do all that was possible to meet them in a conciliatory spirit and not to throttle the industry by unnecessary restrictions, as it might prove to be one of the greatest industries of the country. The manner in which the Author attacked road-authorities, however, was not justified, and to argue that good roads had not been and could not be made by present methods was questioning the ability of those road-engineers—members of The Institution—who had devoted a great part of their lives to the special study of the subject. Notwithstanding the Author's statement that road-authorities had done little or nothing towards the improvement of the roads, Mr. Wakelam, by the figures he had given, had endeavoured to show that the county councils of England had done a great deal towards their improvement. Although figures did not prove exactly that the money had been wisely spent, Mr. Wood thought that the condition of many of the principal roads in the country bore witness to the great improvements which had been made. With regard to tar-paving, many road-

Mr. Wood.

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Mr. Wood. surveyors had had considerable experience with it 20 years ago: it was nothing new. It had not proved so satisfactory as probably the Author might lead people to believe. One case had come under his notice where tar-macadam had been laid down and had had to be taken up and replaced by ordinary macadam. The cheapest method of treating the roads with tar would add at least £22 per mile to the cost of maintaining them, equal to 1*d.* in the pound on the rateable value in the county which he represented (Sussex). Road-authorities were in most cases anxious to assist in remedying the dust-nuisance; but for motorists to demand that the ratepayers of the country should provide better roads by increased rating for their convenience, so that they could travel with the maximum of speed and comfort and the minimum of expense, was considered to be unreasonable. The Author, in his statement of road-resistances, had classed average macadam with asphalt and wood pavements, and had said that the only conditions under which the resistance exceeded 40 lbs. per ton appeared to be on roads having a very soft crust. By inference it was to be concluded that good macadam roads were better than asphalt or wood pavement. The diagrams showing the cambers of what the Author considered a badly-constructed road and a perfect road appeared to be somewhat extreme cases. Mr. Wood had not seen any road 24 feet wide with a 12-inch camber, nor any, except perhaps a wood-paved or asphalt road, with a 4-inch camber. It would be interesting to see the effect of 4 years' wear under moderately heavy traffic on a road such as was shown in *Figs. 11*, C. There must be of necessity a maximum and minimum camber to allow for reasonable wear and tear. He could not suppose that the Author was serious in his statement that the cavities which formed so quickly on macadam roads were due to water-binding—whatever that might mean—unless he considered that the specific gravity of stone was not greater than that of cork, and that stone would float on the water, and settle down when the water flowed away or evaporated. It was refreshing to know that the Author believed that if motor-cars were constructed on correct principles a considerable share of the present odium attached to them would be removed without any further modifications of road-construction, and Mr. Wood might add, as a motorist and a sufferer, that if motorists would try to carry out the law, there would be few complaints. The Author also stated that if the cars were constructed in the manner he suggested, and if tar-paving were used for road-surfaces, the dust nuisance would disappear entirely. He was not so optimistic as the Author, as he did not believe for a moment that the dust nuisance would be eliminated, whatever was used on the roads.

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Mr. Wood.

That no efficient or economical method of treating road-surfaces had been so far found, he said, was proved by the fact that a Committee had been appointed to consider the question and to conduct experiments. When the results of those experiments had been published, a fair division of the cost as between the road-user and the ratepayer had been arrived at, and improvements on scientific principles had taken place in motor-vehicles, authorities, and surveyors in particular, would be only too anxious to do all they could to make the highways of England second to none. He desired for a moment to deal with the question of traction traffic, because he wished the Author to give a little more information with regard to Tables VI and VII. He found in one case that an average load of 8 tons one way cost per mile 1·78*d.*, whereas in the other case it cost 1·5*d.* The figures which the Author gave as the cost per annum in Table VII seemed to differ consistently from those in Table VI. The wages were £5 less, and the fuel was £3 10*s.* less. Gas-coke was priced at 8*s.* per ton, though Mr. Wood doubted whether it could be obtained at anything like that price, as he himself was now paying 16*s.* per ton. The lubricants in Table VI cost £8 16*s.* and in Table VII £5; the maintenance and depreciation was given in round figures at £100 in Table VII, which looked rather like a guess, and in Table VI depreciation at 20 per cent. was £130, and maintenance £39. The rent of wagon-shed was shown at £26 in one and £25 in the other. All the figures seemed to point to some reason for showing that the working-cost of the steam-wagon in Table VII was less than that in Table VI. He had used heavy traction-engines for more than 6 years in hauling road-material under perhaps the most favourable conditions, where the stone was unloaded from steamers by a steam travelling crane and grab direct into the railway-trucks, taken to the railway-station, and hauled out directly on to the road; yet he could not do the work under 3*d.* per ton-mile, whereas the Author showed the cost in Table VIII as 1*d.* per ton-mile. The Author had taken the average daily mileage at 30 miles; whereas unless there was a return load, the earning mileage of that traction-engine would be only 15 miles: consequently the ton-miles per annum should be halved, or the cost per ton-mile doubled. Mr. Wood had often hired traction-engines, but he had never been able to obtain them at less than 6*d.* per ton-mile. According to his view he was saving 100 per cent., but according to the views of the Author the contractors were making about 500 per cent. profit. He would be glad to give the Author all his work at 100 per cent. profit and thus save 50 per cent. for his council.

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Mr. Smith. Mr. E. SHRAPNELL SMITH thought it was a reflection of the present-day movement in motor-traffic that so much of the Paper was devoted to the commercial side. The number of motor-omnibuses in London, which at the time of the preparation of the Paper was 700, had now increased to 874, an increase of 174 in about 3 months. Notwithstanding the financial difficulties and other troubles which had confronted many of the companies, both motor-omnibus companies and the older companies which had part horse-plant and part motor-plant, not a single company in London had any intention of going back to horsed vehicles, as they recognized that the public would have the mechanical vehicle. Therefore he was sure that engineers would be pleased to know that, notwithstanding the period of discouragement that had existed in the motor-omnibus world, a further large extension of motor-omnibus traffic in London would unquestionably take place. In connection with heavy traffic there was no more important question than the permissible weight. In the days of the 3-ton limit, it was impossible to use steam-wagons with any success. After 5 or 6 years of effort the Government, after appointing a special Committee of the House of Commons, over which Mr. Hobhouse presided, granted an increase of tare to 5 tons, and adhered to the definition of the weight unloaded as the weight exclusive of fuel, stores, water, or anything else carried for the purpose of propulsion. He regretted to see that the Royal Commission on Motor-Cars suggested that there should be a change of that rule, and that the weight of a motor-vehicle unladen should be defined as inclusive of fuel, water, accumulators, or other stores. Such a change would be a serious drawback. When it was remembered that from the point of view of damage to the road the weight per axle, or intensity of load per unit width of tread, was of great importance, it would be a pity to modify the Motor-Car Order to allow the tare weight to include the stores. So long as the weight per axle was limited, he thought nothing more was called for. The Author quoted figures which showed that for average macadam the road-resistance was 75 lbs. per ton and on wet macadam 90 lbs. Mr. Smith had to use steam-wagons on all kinds of road, but he had seldom, if ever, met that class of macadam. "Wet macadam" was a generic term. While he had never been able to make road-resistance experiments, other than those in which he had been associated with Dr. Hele-Shaw on the Committee alluded to in the Paper, he had had the opportunity of making practical comparisons of fuel-consumption extending over many months, on a certain road 40 miles long, consisting of 28 miles of macadam and 12 miles of sets. His

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experience was that in the winter the fuel-consumption was often 2½ times as much after prolonged rains as in dry weather. All owners of motor-wagons knew that the difference in the road-resistance, *qua* the wear and tear of the wagon and the fuel- and water-consumption, was much more serious than a matter of 20 per cent. He was sure the Author would agree with that. With regard to road-maintenance and road-making, nobody knew better how to make roads than county surveyors, but he realized the difficulty of getting the money to make them as they would like to make them. Reference had been made in the discussion to the mosaic paving which was used on many German roads. He had endeavoured to find out how that pavement stood in various parts of Germany, and he had found that for a 21-foot road it would cost more than £3,000 per mile. Even with a 15-year life and with practically nothing paid for maintenance, that worked out at something over £200 per mile per annum, which he was afraid, promising as was the material, would be too high to allow of its use. Further, when investigating the question in Westphalia and other parts, he had not been able to find that an axle-weight of more than 3 tons had been imposed upon the material, nor could he find that a single, heavy propelled vehicle had passed over such paving. That question, however, was likely to be settled by a stretch of road laid near Stockport, where heavy steam-wagons and traction-engines were running over the "Kleinpflaster," or mosaic pavement, without pulling it up. He had hoped the Author would say a word or two on gearing and acceleration, a question which was tending strongly to come to the front in connection with public-service vehicles and others, and on the question of gradual acceleration other than the step gear or sliding type. Perhaps that subject would call for investigation in the future. He had never been able to see how the fuel difficulty was going to be met, but in conversation with one of the principal East Indian oil magnates he had asked a question which he thought deserved to be considered. That gentleman complained that all his tank-space was now full of kerosene, whereas 6 years ago it was full of the lighter distillates; and he asked him why, instead of raising the price of every kind of oil until it looked as though the day was near when 8*d*. per gallon would be paid for kerosene, there could not be two prices for paraffin, one for fuel and one for lighting, following the precedent of charges for electricity.

Mr. Smith.

Mr. Carl Oppermann observed that the Author had been good enough to give as an example of an up-to-date electric vehicle a little carriage which he had recently designed. In the Table given of the relative cost for fuel of two petrol-carriages and the electrical vehicle

Mr. Oppermann.

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Mr. Oppermann.

there was apparently a very large difference in favour of the electrically propelled vehicle, and he would like to give some explanation of that somewhat remarkably low cost of the fuel. The electric vehicle in question was only intended for use in towns, and its maximum speed, which was quite sufficient for the streets of London, was about 14 miles per hour. To propel the carriage at that rate three units of electricity were required. It was possible to purchase electricity from some of the central stations in London at as low a price as ½*d.* per unit, provided current was not taken at the peak of the load; and with a system of electric vehicles there would be no difficulty whatever in arranging to take the load at times convenient to the supply stations. It was also quite possible to generate electrical energy at ½*d.* per unit by putting down one of the later suction gas-plants, or even such an engine as the Diesel engine. He had been making some inquiries relative to two very large Diesel engines which had been running about 3 years, and he found that the total cost of their electricity per unit came out at 0·3*d.* In considering the economy of working the electrically propelled vehicle it was necessary to bear in mind that there was no gear, in the ordinary sense of the word. In the vehicle the Author had mentioned the drive was simply by chains. There was one chain-pinion which drove from the motor-spindle to the intermediate shaft, and on each end of the intermediate shaft there was another chain-pinion, which drove on to the hind wheels of the vehicle. All the chains were in dust-tight gear-cases, and the small amount of lubrication necessary would surprise most people whose only experience was with petrol-driven cars. One quart of oil would last an electrically driven vehicle for 12 months. From inquiries he had made of many of the motor-omnibus companies it seemed that the oil they used was a very serious item, and formed a large portion of their total expenses. A great deal had been said about the cost of batteries, many people contending that the expense of their upkeep was prohibitive. The electric battery nowadays was simply made of lead in some form, and after all the useful work had been taken out of the positive or negative sections the lead still remained, and could be melted and used again. His own experience showed that it was possible to obtain a run of 4,000 miles from a set of positive plates costing about £8. He did not give that sum as being the price that a private user had to pay; he was speaking, from a commercial point of view, of the case of a large number of vehicles being used by one company. The negative plates lasted nearly twice as long as the positive. In a recent discussion on the petrol and electric systems

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a great deal had been said about the trouble met with in a continuous-current system in connection with the brushes and the commutators. Well-designed brushes and commutators in a continuous-current motor gave very little trouble indeed, provided that the motor was not subjected to the shocks of the road. He had seen electric vehicles in which the motor was clamped directly on to the back axle of a carriage running on solid tires, and a motor under those conditions naturally received the whole of the shocks from the road; whereas if the motor was suspended on the body of the carriage over the springs those shocks would be almost entirely eliminated. There was no difficulty in designing a continuous-current motor with brushes which would give little trouble indeed, and would require little or no attention for months together. Mr. Oppermann.

Mr. D. J. Smith was pleased to see that the Author had mentioned the Brayton engine, but he was afraid there was not much to be expected from that engine. Experiments he had conducted in 1899 and 1900 showed that, owing to the very high temperature and the great loss that took place, the fuel could not be used to the same advantage as by taking the gas into the cylinder and compressing and exploding it. Some engines were now compressing the gas first into the receiver and using the compressed gases in cylinders on the two-stroke cycle, but he believed there was nothing to choose between that and the present Otto cycle. He did not think that the test of a White steam-engine and boiler could be regarded as a fair test of what steam really could do and was doing. For instance, it would be readily seen that the heating-surface of the boiler was insufficient, there being only practically 12 square feet of heating-surface in the generator. The temperature of the waste gases must be exceedingly high. Also, there was no feed-water heater used on the exhaust steam. Where the heating-surface was better proportioned to the work to be done in the flash-boiler, much better results could be obtained. In burning paraffin oil under a flash-generator having 85 square feet of heating-surface an evaporation of 18·5 lbs. of water per pound of fuel had been obtained, considerably in advance of the figures given in the Author's Table. The steam-temperature given was not as high as that generally used in steam-car practice; steam at 763° F. was not called highly superheated, and several cars were now using steam at 1,000° F. and over. By using that high superheat much greater economy was attained than that given by the Author. On a smaller engine, not a compound engine, using superheated steam of about that temperature, a consumption of 9·8 lbs. of steam per brake horse-power-hour had been obtained, which worked out at about 0·59 lb. of fuel per Mr. Smith.

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Mr. Smith. brake horse-power-hour, and that compared very favourably with the figures given by the Author for an internal-combustion engine. He thought engineers did not generally recognize the great debt the steam-engineer owed to those who had evolved the steam-car. The present steam-car represented steam-practice as it would be 10 or 15 years hence. Steam was still the prime mover, and was now being used at temperatures which were thought impossible a few years ago. The consumption had been reduced to a figure which rivalled that of the internal-combustion engine at its best. The figures given by Colonel Holden represented a practical test of a petrol-engine, but it could hardly be considered a fair test, as the work on the crank-shaft of the petrol-engine was not the work obtained at the road-wheels. There was a considerable loss in the gearing of the petrol-car, whereas in the steam-car engine the power evolved was practically available on the road-wheels. In order to get strictly comparative results the power should be taken from the road-wheels in both systems. Pressures of 500 or 600 lbs. per square inch were now used without any trouble, and the consumption of water and fuel had been reduced to very low figures. That had been achieved only by the use of suitable engines. There was no doubt that the results obtained in steam-practice with motor-cars would in future largely influence steam-practice in both locomotives and marine work. The "suitable engines" he referred to were of the single-acting type. It was not surprising that the type of engine which had been found most suitable for internal-combustion work, where the temperature of the working fluid was high, should also be most suitable for steam of almost equal temperature. Highly superheated steam rendered the satisfactory use of glands impossible, and that was no doubt the cause which had regulated the temperature of the steam in the results given on p. 37. No advantage whatever had been found to accrue from compounding with highly superheated steam, in several heats; an increase of power had been obtained by abolishing the low-pressure cylinder. The work of modern steam-car builders pointed to the fact that in the near future all reciprocating steam-engines would be simple; no double-, triple- or quadruple-expansion engines would be made, as they would give no advantage in economy over the simple engine. The engine of which he had given the consumption was of 5 HP. only. The Author stated that cars using paraffin emitted smell. It was admitted by those who drove both steam- and petrol-cars that the modern steam-car, burning paraffin, emitted less odour than the average petrol-car, and it never emitted clouds of burnt lubricating oil. The Author also stated that paraffin-burners clogged and

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choked very rapidly. This might be the case with some burners, but with the burner used on the Serpollet cars the vaporizer lasted as long as on any steam-car burning petrol, and nipples or jets required cleaning only at long intervals. A filter was provided to arrest all deposits, this filter being very easy to clean when it was required—about once a week. With regard to fuel-consumption, the figures given by one of the leading London omnibus-companies for 40-HP. petrol motor-buses was 4 miles per gallon. A steam-omnibus of similar power, tested officially, had given 7 miles per gallon of paraffin, which cost 50 per cent. less than petrol per gallon. It was a very significant fact that the largest makers of petrol motor-cars in the world, Messrs. Darracq, had turned to steam as a motive power for their omnibuses. Mr. Smith.

Mr. DOUGLAS MACKENZIE observed that some speakers had rather ridiculed the suggestion that the old system of making roads could be improved by using tar and tar-products. Experiments were now in progress showing that the mistakes made in the past had been due very largely to the use of tar in its crude state. Tar was undoubtedly useful as a material to be used for binding granite so as to obtain a thoroughly reliable surface. Roads made with water-binding might be solid enough in dry weather, but in wet weather the whole of the road-crust became a sponge. If a material could be found that would bind the stones together firmly the road would withstand all kinds of traffic. It was necessary to hold the hard material advocated by all road-surveyors rigidly in the road and not allow it to be affected by weather or by the traffic, and that could be done only with a suitable binding material or matrix. Unfortunately, tar was considerably affected by variations in temperature, and therefore it was necessary to alter the nature of the tar, if it was to be used as a binding material for the roads. By distillation many of the volatile products that spoiled the tar when it was first laid could be got rid of, but distillation did not alter the nature of the tar. Something must be added and something taken away, in order to make it consistently the same in hot summer weather and cold winter weather. That could be done only by the chemist, who would have to work at the problem and discover what alterations should be made in the material—at a reasonable cost—in order to obtain suitable binding material for the roads. Mr. Wood had stated that the application of tar—Mr. Mackenzie presumed under the most modern conditions, namely, by spraying from a machine—would add £22 per mile to the cost of maintenance of the roads. He thought Mr. Wood had overlooked the point that the addition of that tar would Mr. Mackenzie.

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Mr. Mackenzie. considerably increase the life of the road and ultimately reduce the annual cost of its maintenance. It was hoped that the time would come when by obtaining suitable materials there would be an actual decrease instead of an increase in the cost to the rate-payers. Allusions had been made to the National Dustless Roads Committee and the experiments they proposed to carry out to see which of the materials suggested for road-construction was most useful and practicable. There was no doubt that some materials which had been tried in small experiments were showing signs that they would be very useful indeed. The Committee's idea was to take a long length of main road subjected to the same traffic throughout, and to lay different materials in fairly long stretches, in order to judge their relative freedom from dust, etc., and their durability. In that way reliable data might be obtained.

The Author. The AUTHOR, in reply, agreed with Mr. Worby Beaumont that the subject was so wide that only a few points could be touched on in the Paper. As there was a tendency among modern automobilists to ignore traction-engine designers and the good work they had done, he had thought it only fair to point out that traction-engine designers, as was naturally to be expected on account of their longer experience, had more nearly approached finality in their designs than was the case either with motor-wagons, the next heaviest type of vehicle, or with the lighter vans and pleasure-vehicles. As a proof of this he would point out that the depreciation-rate actually found to be necessary for traction-engines was far lower than the depreciation-rate found necessary with the more modern self-propelled vehicles. He agreed with Mr. Clarkson that the Table on p. 37 did not put the remarkable performance of the White boiler and engine as clearly as was desirable. As, however, the results shown were so remarkable considering the size of the engine, he had thought it safer to quote the actual figures furnished to him at Cleveland by the White Company, and had therefore copied the Table directly from Professor Benjamin's report. He believed that Mr. Clarkson was correct in supposing that the temperature given as that of the fuel ought to have been the temperature of the "vaporized fuel." With regard to the important figures as to the range of temperature through which the engine worked, it would be seen that the total temperature at the point where the steam entered the engine was 695° and the temperature at the exhaust was 288°. The temperature-range in the engine-cylinders was therefore not 347° as stated by Mr. Clarkson, but 407°. This gave the very considerable temperature range $(T - t) / T = 0{\cdot}35$, which was an extraordinary range for a steam-engine, and which, in the Author's opinion, would have been

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considerably improved if the temperature of the steam entering the engine had been as high as 900°, giving a range of 712° in the engine-cylinder. The Table did not show that the engine was a compound engine, but from the known cylinder-dimensions the ratio was 3·6 to 1. From the Author's notes taken at the time it would appear in this case that the boiler-efficiency was 80 per cent., and the total efficiency of the engine and gear was 54 per cent. of that of a perfect engine working between the same ranges of temperature. These results would have been improved if, as stated above, the temperature-range had been increased to what was now known to be perfectly possible without any fear of carbonizing the lubricating oil; and if, as Mr. Clarkson had suggested, mushroom valves had been used instead of the slide-valves actually used by White, they would have allowed an earlier cut-off and better steam-distribution, which would doubtless have given still better results. He was glad to see that Mr. D. J. Smith, who had had great experience with steam-engines using steam at very high temperatures, considered that Professor Benjamin's test did not represent anything at all wonderful, and that better results were likely to be obtained in the immediate future from the higher temperatures and better distribution of steam by lift-valves. Mr. O'Gorman's criticisms of the Author's comparison between the cost of steam- and petrol-driven cars shown by Tables I and II, in the second part of the Paper, depended chiefly on his view, which was partly supported by Mr. Dugald Clerk, that 5,000 miles per annum did not fairly represent the average running of a modern touring-car. The Author, however, had adopted this figure because the Daimler Company agreed that it was a fair figure to take, and reasonably representative of the average distance run by the larger number of cars in private hands. Mr. Dugald Clerk said he had run his car 7,500 miles, and that he had known cases where 15,000 miles were run. This might be true, but the Author still thought that 5,000 miles was a representative figure for men who used their cars in the ordinary way. Without doubt such increase in mileage would alter certain of the figures compared, notably the items for repairs and depreciation, but this would not notably affect the comparison in the cost of fuel, stores, or tire-replacements, nor would it greatly affect the comparison in total cost. It was necessary to repeat that the depreciation, which might be said to include the interest-charge, was taken at the fixed percentage of 15 per cent. on the list price of both cars, which were representative of the most modern types, the accommodation for passengers and the weights carried being identical; so that the comparison was in all respects a fair one.

The Author.

Referring to Colonel Holden's criticism, the writer in *The Autocar*

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The Author. who signed himself "R" was Lord Russell, who had given permission to the Author to mention his name. He had given the comparative cost of running for the two systems, as he was the owner of a White steam-car and of a Daimler petrol-car, nearly identical in power and size. Lord Russell stated that his letter simply gave the aggregate cost of the two cars, no attempt being made to separate the cost, but that in such cases as he was able to differentiate, the cost was in favour of the White steam-car, in respect of fuel, tires, repairs, and depreciation. With regard to Colonel Holden's statement that during the recent French War-Office tests, the steam-cars of the Serpollet type used twice as much fuel as the average petrol-cars, and three times as much as the best petrol-car, the Author had made inquiries and had found that Colonel Holden was mistaken in thinking there had been any attempt to compare fuel-consumption on equal terms; and that the loads carried, and the speed at which the steam-cars travelled, were so greatly in excess of those of the petrol-driven cars that no real comparison could be made. Moreover, the French authorities had given a prize to Mr. Serpollet for the good performance of his cars. It was a pleasure to argue the academic question of air-resistance with Colonel Holden. Little was known of this very interesting subject, and it was very necessary that further experimental work should be undertaken. Colonel Holden argued that the Author's figures, worked out from the results of the Tourist Trophy Race of 1906, did not throw any light on this point, as they were based on a petrol-consumption of 0·83 lb. per brake horse-power-hour, which, in Colonel Holden's opinion, was far too low an estimate. It followed, therefore, that Colonel Holden considered that the Author had overestimated the power, and in this way had overestimated the air-resistance; but Mr. Dugald Clerk had taken much lower figures, namely 0·57 lb. of petrol per brake horse-power-hour as a correct figure for a first-class petrol-engine. It would be seen that the Author's figure was sufficiently above Mr. Clerk's figure to be very probably a correct one. It followed that, if this was so, the Author's air-resistance figures had every probability of being correct; for, it must be observed that, as Colonel Holden admitted that he was in agreement with the Author as regarded the axle- and road-resistance, if the Author's total power figures were fairly correct, those given for wind-resistance must also be fairly correct. He was glad to note that Mr. Campbell Swinton's figures corroborated his own very closely. Mr. Swinton was to be congratulated on the excellent results obtained with the Bath motor-omnibuses. The figures were below the average for motor-omnibuses used in country districts, although he agreed with Mr.

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Swinton that the country near Bath was exceptionally hilly and the roads bad, which would tend to add to the cost of running. Mr. Dugald Clerk's remarks were, as would be expected, of great interest. He had stated that 0·58 lb. of petrol per brake horse-power-hour was a result now obtainable with a good petrol-engine, and had brought this into comparison with the results shown in the Table on p. 37 of a steam-car by Messrs. White, which showed 0·975 lb. 4 years ago, and this result, the Author was informed, had been further improved upon. When the greater range of temperature was obtained which was referred to above in the reply to Mr. Clarkson, and which Mr. D. J. Smith and others had shown did not present difficulties in working, it was reasonable to believe that the fuel-consumption of steam-cars would be very slightly if at all in excess of that of the internal-combustion-engine car, even if the transmission-losses were equal; but as the transmission-losses were usually much less in the case of a steam-car, and further, the fuel used was notably lower in price, the steam-car certainly compared favourably with the internal-combustion car as regarded cost of fuel. In regard to the use of worm-gear, it was true that Mr. Lanchester had used it for some time, but for a long time he had been the only user of worm-gear. It was only within the last year or so that several other designers had adapted worm-gear to the driving of motor-vehicles. The Author.

Mr. Wakelam's remarks must naturally carry great weight. As the County Surveyor of Middlesex he surely ought to know how far the upkeep of roads had been affected by the recent development of motor-car traffic, but the Author would point out that the rapidly increasing figures quoted by Mr. Wakelam could not be due specially to the increase of motor-cars, but were due in part to the increase of population, and to the greatly increased mileage of vehicles of all classes traversing the Middlesex roads. He was glad to find Mr. Wakelam was in agreement with him as to the effects of climate on the roads. Mr. Wakelam did not appear to attach much value to tar as a material for toughening the top of the road, but this was a question on which the results of the further experimental work must be awaited. In regard to Mr. Wood's remarks, the Author deprecated the idea that the Paper was in any sense an attack upon road-surveyors. It was necessary to repeat the fact that very little more money was spent on the roads now than a few years ago when the roads were hardly used at all. No one could deny that the methods of maintenance still followed were antiquated, and that in far too many cases the roads were spoilt by excessive camber, excessive use of hogging or binding material, and the use of too much water at the time the rolling was carried

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The Author. out. Mr. Wood had taken exception chiefly to these statements in the Paper; but could give no categorical denial to any of those charges, and doubted if tar would be a perfect remedy. No one had said this had yet been fully proved for all cases, but the experiments in Battersea, on the Thames Embankment, on the Bath Road, and in many places in the county of Kent, had shown that greatly improved results were obtainable by the substitution of tar for water as a binding material. Mr. Wood had taken exception also to the Author's use of the term "water-binding." Apparently this referred to the sentence on p. 15, "Hitherto road-makers have relied on water as the binding material to enable them to consolidate the road-surface." The meaning of this sentence appeared to be fairly obvious. It was not denied that it was now the practice to use considerable quantities of water at the time the road was rolled: and this had not been the case in McAdam's time. The material was then put on nearly dry and allowed to consolidate itself under the traffic. If nowadays the material were put on dry and rolled dry with little or no hogging, the rolling would take longer and be a little more costly, but the results would be greatly improved, as had been shown by the excellent results obtained by the Office of Works quite recently in remaking the north-to-south road across Hyde Park. Mr. Wood appeared to have had very unfortunate results as regarded the cost of his traction-engine haulage. It was difficult to understand why his hauling work should cost him so much more than it had cost the other users from whom the Author had obtained his information. With reference to Mr. Shrapnell Smith's question why the Author gave 75 lbs. per ton as the rolling- and axle-resistance on average macadam and 90 lbs. for wet macadam, he understood that Mr. Smith thought that, as the fuel consumed in wet weather after prolonged rains was 2½ times as much as in dry weather, this was wholly due to road-resistance. The Author thought he could partly account for this excessive fuel-consumption. The early motor-wagons used coke as a fuel, and coke being absorbent, in wet weather its calorific value was very largely reduced: but apart from this, Mr. Smith was undoubtedly correct in stating that at certain times the rolling-resistance observed on macadam roads in a soft state might be nearly twice as great as on the same road in the best possible condition. He was in thorough agreement with the remarks of Mr. Mackenzie, who had studied the matter very closely, as to the mistakes which had been made during the early experiments with tar on the roads. Mr. Mackenzie had virtually answered many of the points raised by Mr. Wood as to the effects and cost of tar-spraying; and as Mr. Mackenzie was taking a leading

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part in the important experiment that was now about to be commenced, the Author hoped that at a no very distant date he would communicate to The Institution the results of the experiments on this important subject of toughening the top of the road by tar or means other than by water-bond. He believed that the inception of the National Dustless Roads Committee was largely due to Mr. Mackenzie's exertions, added to those of Mr. Maybury, the Kent County Surveyor, whose work in this connection must always be remembered. The Author agreed with Mr. Shrapnell Smith that it was of great importance that the use of the heavier petroleum products, such as the kerosenes and the still heavier oils, should be encouraged as much as possible. He welcomed Dr. Hele-Shaw's contribution on the fuel question, which he agreed was of extreme importance. The difficulties of using the cheaper oils were more considerable than appeared at first sight. The cheaper fuels were extremely rich in combustible matter, but unfortunately their composition was very irregular, especially in regard to the quantity of carbon liable to be deposited in the vaporizer during the act of vaporizing them. Probably the true solution of the problem of burning this class of fuel was to atomize it mechanically and to burn it by spraying it over heated surfaces. He agreed with Dr. Hele-Shaw that Mr. Diplock's experimental "pedrail" wheels were of the highest interest; but, as far as he knew, the pedrail had not, up to the present, been working on a sufficient commercial scale to enable opinions to be offered as to its durability. Dr. Brightmore's method of applying an engine to any vehicle in the form of a turn-table was excessively ingenious, but, as far as the Author understood, the matter had not yet got beyond the experimental stage. Mr. Carl Oppermann was practically the only speaker on the side of electrical vehicles, which, as stated in the Paper, the Author believed would have a great future. He congratulated Mr. Oppermann on the excellent results he had been able to show as to the cost of the electrically-driven vehicles, and on the long service of 4,000 miles he had obtained from a set of positive battery-plates, as it was undoubtedly the case that one of the largest items in the running-cost of this class of vehicle would be the cost of renewing the positive plates in the batteries. He agreed with Mr. Oppermann that there was no difficulty in designing a continuous-current motor so that the brushes would give very little trouble under the conditions of use on roads.

The Author.

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Correspondence.

Mr. Aveling. Mr. THOMAS C. AVELING remarked that the Paper formed an excellent corollary to that read by Dr. Hele-Shaw[1] before the Institution of Mechanical Engineers in 1900, and now brought the matter up to date. It was to be regretted, however, that as the Paper dealt with modern motor-vehicles and the latest types, no illustration was given of a gear-driven motor-wagon, seeing that several of this type were made by some of the foremost firms in the country. The question of chain- versus gear-drives was an old one, and each, of course, had their advocates; but there was no getting away from the fact that chains stretched, and especially in heavy motor-wagon work, where the severest strains met with were not those encountered in ordinary running on hard roads, but when the wagon was in difficulties, owing to soft ground or bad roads. Users were often tempted, in delivering a load, to run the vehicle over soft ground, which frequently resulted in the wagon sinking to the axles. The enormous force imposed upon all parts when endeavouring to steam the wagon out of the hole, subjected the drive to severe stresses; this was the time when the chain or gear was put to its severest test, and should the chain break, great trouble would be experienced; whereas with gear-drives of first-class design and workmanship, he had never yet known the gears to strip or fail to do their work effectually. Figs. 8, Plate 2, showed an interesting type of heavy motor-wagon, but surely it could hardly be economical to use steam at 250 lbs. per square inch in a simple engine: the pressure and temperature of exhaust would be comparatively high, and the full advantage of the high steam-pressure would, to a certain extent, be lost; and the amount of steam used by this engine when hill-climbing or in cutting off at half stroke would be, in ordinary every-day working, fairly considerable, resulting in increased consumption of fuel and cost of working. Another noticeable feature was the absence of a bearing between the two cranks of the engine, and whilst this was compensated for to a certain extent by increasing the length of the two bearings fitted, it would entail heavier wear on these bearings, more especially on the one nearer

[1] "Road Locomotion." Proceedings Inst. Mech. E., 1900, p. 185.

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the chain pinion, seeing that all shocks transmitted by the chain could be felt in this bearing. The traction-engine shown in Fig. 9, Plate 3, no doubt was an efficient one, but much greater simplicity and ease of access could be obtained by fitting outside valve-chests to the compound-cylinders, reducing the simplicity very nearly to that of a high-pressure engine. In connection with motor-tractors, it was desirable to make these engines as near to their prototype, the heavy traction-engine, as was possible, and all complications of multiplicity of cylinders should be avoided. Mr. Aveling.

Mr. E. H. G. Brewster drew attention to an old invention relating to automobiles which had never been described or alluded to in any work dealing with motors or gas-engines, so far as he had been able to ascertain, but which, from an historical point of view, was of interest, as it was probably the earliest recorded instance of an attempt to devise an automobile to be worked by a gas-engine, the explosive mixture in the cylinder of which was fired by electricity. The inventor was one Major de Rivas; and a full description of the machine was given in the specification of his patent, which was granted just 100 years ago, the date of it being January 30th, 1807. A copy of the specification was in vol. ix, p. 182, of the French patent specifications, which could be seen at the English Patent Office Library. Mr. Brewster.

Mr. E. A. Calvert observed that the Author had put forward several statements to show that the use of the steam-engine was more advantageous for the propulsion of automobiles than that of the internal-combustion engine. Although he was of opinion that steam before long would supersede all other powers now in use, still there was one of the Author's statements which he thought required modification. That statement was that gearing and the means to provide for the change of its ratio was necessary for the variation of speed in the case of the internal-combustion engine, while in the case of the steam-engine no such gearing was required. He would like to ask the Author if he was aware that internal-combustion engines had been constructed so that their speed could be altered, and also that they could be reversed just as efficiently and as quickly as steam-engines. To give one example, he would mention a few particulars of an internal-combustion engine constructed to overcome the difficulty of reversing and varying the speed, the design of which he had been employed on, and which was the invention[1] of Mr. J. D. Roots. This engine was a two-stroke-cycle continuous-combustion engine, having a two-diameter Mr. Calvert.

[1] British Patent No. 25,983 of 1905.

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Mr. Calvert. piston and one impulse to every revolution of the crank. Its exhaust valve, which worked mechanically, opened near the completion of the power-stroke and closed near the termination of the pumping-stroke, which ensured a minimum amount of clearance at the end of the stroke in the cylinder and also prevented too sudden a fall in the pressure and the temperature of the hot gases entering the cylinder. Variation of speed and the reversal of the engine were effected by the employment of a special valve for the admission of the gases to the cylinder, its movement being regulated by means of cams and a roller connected with the main shaft. In addition to this, the engine had a special feed-valve, and its speed could be varied by this valve also. The valve for the admission of gases was of mushroom type, and was placed in a horizontal position immediately above the cylinder and between it and the continuous-combustion chamber. On its spindle were two disks of nearly equal area, so that a small amount of power only was required to move it. The travel of the valve was varied by its spindle receiving motion transmitted to it through a bell-crank, held by a spring and a vertical spindle which had a specially shaped end to rest on a roller, by means of cams shaped to give the cut-off and fixed on the main shaft. The roller above mentioned was held by a fork, and the other end of this fork, remote from the roller, had an eccentric strap fastened to it which worked on an eccentric attached to a sleeve, which, by a handle, could be made to slide on a countershaft placed parallel to the main shaft. The cams on the main shaft, besides being shaped to give a gradual cut-off, were made such that if the roller were moved one way along the axis of the main shaft, it was on the cam giving forward motion to the valve, and if moved in the opposite direction, was on the cam giving reverse motion; and since the eccentric-strap, when moved by a handle fixed to it, altered the travel of the roller in a direction at right angles to the axis of the main shaft, the rise of the vertical valve-spindle, and hence the travel of the valve itself, could be altered in relation to the time of revolution of the main crank as required. The special feed-valve was also of mushroom type and had a mixing-chamber under it, the bottom of which was a perforated disk through which the air-charge was driven by the power-stroke of the piston. Between this valve and disk was a petrol injection-valve, the spindle of which was connected to the spindle of the main throttle-valve of the engine in such a way as to open this petrol-injection valve or shut it in proportion to the opening of the throttle-valve. By this means of connection between throttle- and petrol injection-valves and the form of the feed-valve and mixing-

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chamber being combined, it was clear that not only could the speed of the engine be varied by altering the richness of the mixture, but also no carburettor was required. On p. 8 mention was made of the introduction of superheated steam and the use of the flash-boiler in applying steam as the motive power for automobiles. His present firm were constructing vehicles on this system; they employed 700° to 800° of superheat and used as fuel ordinary paraffin oil; and since it was practically impossible for explosion to take place, this was far safer and more advantageous than the use of the petrol-motor. Mr. Calvert.

Mr. ALEX. CLARK remarked that in the admirable digest of the various forms of motor-vehicles given by the Author, the tram-car had not been referred to as a variety. It had been looked upon as occupying a different sphere, and as being in a sense antagonistic to what were termed "motor-vehicles." Yet the tramcar or railway-carriage might be petrol- or steam- or electrically-driven vehicles, and might be fairly included among "modern motor-vehicles." The motor-tramcar was, like other motor-vehicles, a self-contained unit, and could better be classified with the road-motor or omnibus than with the electric overhead or conduit systems or with the cable-tramways. It required the use of rails on the streets like other tramways, and shared in the advantages or disadvantages of that system to this extent, but it did not otherwise encumber the streets with apparatus, as the power of each car was independent of either wires or conduits. On the other hand, the question of elastic tires which so much troubled the designer of the road-vehicle had no place in the economy of the tramcar, while the steering-mechanism and the question of skidding did not trouble the driver. It was altogether more flexible than an electric tramcar, and was more rigid and less liable to damage than the road-car or omnibus. Adopting the well-known construction of an ordinary tram-car, with a few small changes in the accommodation for passengers and slight alterations on the platforms for the driver and conductor, the chief points to be considered in the construction of the chassis were the driving-gear and the brakes. He had recently studied this problem, with results which would be found embodied in two patent specifications.[1] With regard to the matter of costs, although actual figures were not yet available, he was confident that the capital required, as well as the working-expenses, would be much in favour of the adoption of a system of motor-tramcars such as formed the subject of this patent. Mr. Clark.

[1] British Patents Nos. 5,333 and 5,333a of 1906.

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Mr. Cornock. Mr. J. C. CORNOCK, referring to the three types of steam-wagon, Figs. 6, 7, and 8, Plate 2, called attention to a fourth type which had been in existence since the passing of the Light Locomotives Act of 1896. This was the Mann type, which was closely modelled on traction-engine principles, although the details adopted from traction-engines were not those adopted in Figs. 6. This latter followed the older road-engine in placing the engine on top of the boiler, but departed from it in the style of main frame, and in using a pitch-chain for the driving, while the Mann wagon adopted the traction-engine plate frame, with all shafts carried in brackets spigoted into and bolted to the plate; and it also adopted traction-engine gearing so as to avoid chains. It departed from traction-engine lines in so far that the engine was placed below the platform and was in an oil-bath to make it self-lubricating. In both designs the locomotive boiler was taken entirely from traction-engine practice. It appeared to be a distinct omission on the part of the Author that no illustration was given of a gear-driven wagon, although there had probably been more discussion on the question of chain versus gear driving than on any other feature of steam-wagon design. The justification for the chain lay in its flexibility and silence, but this was largely discounted by the greater cheapness of renewals of gearing, which enabled a user to keep the machine in a condition for quiet running at less expense. On the other hand, gearing was much lighter, and a breakage did not present the same possibilities of a serious accident as a broken chain. A great difficulty with some steam-wagons in hilly districts was their lack of adhesion when unloaded. It had been a common complaint in the past that the wheels slipped on steep hills when returning home empty, and the two designs in Figs. 7 and 8 would, in his opinion, be much improved by placing the boiler behind instead of in front of the front axle, as they not only did not place any of the boiler weight on the driving-wheels, but actually relieved them of a portion of the weight which would rest on them if the boiler were above the axle even if not behind it. It must be remembered that the wagon might have to climb a steep and slippery hill when it was unloaded and also with the water-tank empty. The Tables of working-costs did not appear to be based on results, but to be estimates only, and it therefore seemed a mistake not to have based them on the same conditions for the different types. As examples, Table VI took an average mileage of 56 miles and Table VII of 50 miles. Table VI took wages as £148 and Table VII as £143; Table VI assumed Welsh coal and Table VII gas-coke for the fuel. In Table VI maintenance was given at £39 and depreciation at

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£130, or a total of £169, whereas the two were placed together at £100 in Table VII, although there was nothing in the respective designs to make these items less in the engine referred to in Table VII. There were also differences between the insurance and rent items. No doubt the difficulty with users' actual accounts of running-costs was that very few users kept really accurate accounts, and the personal element entered so largely into the success of the machines that it was impossible to choose fairly the representative user. In view of this he thought it would be much better in a Paper of this description to give an estimate of fair working-cost with reasonable usage, and not to attempt to discriminate between different machines with figures which were purely estimates, and therefore gave a misleading impression of relative merits. Presumably the tractor in Figs. 10, Plate 3, was intended to work under the Motor Cars Act, and not as a traction-engine, and the Author appeared to have overlooked that this required the wheels to be smooth-shod, so that the tractor as illustrated could not legally be used except with all the disabilities of a traction-engine. Mr. Cornock.

Mr. E. H. Cozens-Hardy observed that the Paper was in the nature of a record, and accuracy was therefore desirable. For this reason he desired to draw attention to what appeared to be a serious discrepancy between one of the Author's statements and the figures of tests which he gave. On p. 37, in the "unprecedented results" obtained by Professor Benjamin from tests of a White car-engine, the consumption of gasolene was given as 1·16 lb. per brake horse-power-hour. On p. 24 the Author showed that the two most economical cars in the 1906 Tourist Trophy Race used only 0·83 lb. of petrol per net horse-power-hour. Taking the efficiency of transmission at 88 per cent. as given on p. 30, and neglecting the lower efficiencies when the cars were using their gears (on Snaefell, etc.), the consumption of these petrol-driven cars worked out at 0·73 lb. per horse-power-hour in an actual road trial, as against 1·16 lb. per brake horse-power-hour for the steam-driven engine obtained in what appeared to have been a laboratory test at full-load. The difference between 0·73 lb. and 1·16 lb. was 0·43 lb.—that was, the consumption of this specially good steam-driven car-engine under the most favourable laboratory conditions was more than 58 per cent. in excess of that of the two petrol-driven car-engines in an actual road trial. This result from the Author's own figures appeared to contradict his statement that "since the days of the flash-boiler and superheated steam, the consumption of the steam-driven car is probably not more than 15 per cent. in excess of that of the petrol-driven." It was true that the excess of 58 per cent. related to Mr. Cozens-Hardy.

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Mr. Cozens-Hardy.

engines and the 15 per cent. to complete cars, but no conceivable difference in the efficiency of transmission could account for the 43 per cent., by which the Author appeared to have been too favourable to the steam-driven car in respect to petrol-consumption. With the present rising prices, petrol-consumption was not an unimportant factor. The Tables of working-costs were evidently not meant to be comparative, as it would be entirely fallacious and misleading to compare the annual costs for the 28–30-HP. petrol-driven car with those of the smaller 20-HP. steam-driven car. With regard to the power which horses could exert, it was perhaps worth recalling that in the Report of the Select Committee on Steam Road-Carriages in 1832 (whose far-seeing recommendations had been so lamentably neglected by Parliament), Telford stated that the coach from London to Birmingham was regularly covering the 111 miles in 8 hours, including all stops for changing horses. The maximum speed appeared to have been 15 miles to 17 miles an hour over certain stages, and taking the figure of 2½ tons to 3 tons as the average weight of a laden coach as given in the Report, and 100 lbs. per ton as the rolling- and axle-resistance—a low estimate for the old gravel roads, judged by the Author's figures for modern macadam—the four horses must have been in the habit of working at the average rate of 3·2 HP. each over these stages.

Mr. Hawkins.

Mr. J. Fred. Hawkins observed that when the Statutory Rules and Orders of the Heavy Motor Car Order, 1904, were issued, county surveyors and all road-surveyors welcomed Article VI (1), paragraph 3, which stated—

> "Provided also that, if the tyre is constructed of separate plates, the plates may be separated by parallel spaces, which shall be disposed throughout the outer surface of the tyre so that nowhere shall the aggregate extent of the space or spaces in the course of a straight line drawn horizontally across the circumference of the wheel exceed one-eighth part of the width of the tyre,"

but there was nothing in the Statutory Rules and Orders as to how the renewals of these plates were to be effected. Only last summer he noticed the crust of a weak macadam road cut into at spaces of a few feet, and could not make out what had done the damage until he came up with a heavy motor-car, and found that a plate which had come off had been replaced by a new one of the original thickness; thus in each revolution the whole weight of the wheel came on to this one plate, and the road being dry, the surface was completely broken. On p. 24, the Author said, "Finally, strips are riveted across them diagonally, with small spaces between the strips, according to conditions carefully laid down by the Local Government Board"; but these conditions did not embody any instructions

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as to renewals. He thought when the Local Government Board were considering clauses for a new Locomotive Act, a clause as to renewals ought to be inserted, as enormous damage could be done to a road by one plate projecting beyond the others. Mr. Hawkins.

The LANCASHIRE STEAM MOTOR COMPANY communicated the following observations:—Seeing that this Paper, over which the Author had evidently taken so much trouble, would probably be looked upon as a standard for reference, it would be well to point out what an important part the improvements in steel-manufacture had played in developing the motor-bus. The firm very soon discovered that material which was perfect in a steam-wagon was useless when applied to the sliding change-gears of a motor-bus. It had only been by experiment and by the use of expensive steels and careful hardening with the help of electrical recorders that the present very satisfactory gears had been produced by them. An important improvement in omnibus work was one which they and a few other firms had adopted, that was, a pressed steel frame, which they made from a nickel-steel. They had also done away with the transverse spring at the back, which, with a heavy top load, was thought by the police to produce too much swaying. They believed that the double chain gave the best results for motor-wagon work; the long single chain was more liable to get into trouble, and when it did, the wagon was useless till it was repaired, whilst with two chains it was possible to lock the differential gear and work with one chain. They did not use the chains for omnibus work, because above 8 miles per hour it was not possible to have a quiet roller-chain, and Mr. Renold himself did not advise the use of the silent chains in exposed positions. They had found them unsatisfactory for motor work as a final drive. They preferred the bevel drive to the worm for several reasons, among them being the fact that it made a more central drive, so that the outer tube over the propeller-shaft could be used to transmit the thrust, and all side-rods, perches, etc., were dispensed with. They placed the differential gear on a countershaft and geared on to the axles about 3 to 1, which was a much better arrangement than placing this gear on the live axles, as these in time were bound to get a little out of line, as the outer bushes wore under load. They had an improved method of engine-lubrication which there was not space to explain here, but which entirely got over a smoky exhaust under all circumstances. It was impossible to over-lubricate with it. The costs of running petrol-drawn motor-omnibuses appeared to be corroborated by what figures they had. Taking the steam-wagon, the ideal system was when the driver did not know he had an engine on his wagon at all. This could The Lancashire Steam Motor Co.

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The Lancashire Steam Motor Co.

never be realized by the method of fitting an exposed engine, requiring constant oiling, on top of the boiler, where it was exposed to coke- and road-dust and wet. Their engine was practically non-adjustable and was boxed up in an oil-bath. Many drivers of their wagons had never had to open their engine-cases at all, and left that for the periodical inspection by a competent fitter. The live axle was not so good for wagons, as they did not run on rubber tires, and the vibration was such that with the continual reversal of stress, fatigue and gradual fracture which was set up, axles often failed with no load on the wagon. The best axle, in their opinion, was the solid-drawn tube. A large platform was a very important point. In a few cases what the Author said might be true, and it might be possible to use larger wheels; but, generally speaking, customers would not look at a wagon without the ordinary flat platform in common use with horse-traction, and they wanted it larger than with horses. The area of the platform they generally fitted was 94 square feet, and this was much bigger than could be fitted when a boiler of the locomotive type was adopted. The vertical fire-tube boiler, when properly built, was perfectly satisfactory and required re-tubing on account of the corrosive action of the water long before there was any trouble from leakage at either tube-plate. It was lighter and cheaper to build and repair than the locomotive, and was not so liable to damage by careless handling, and the efficiency was good. The evaporation they obtained with steam at 200 lbs. was 9 lbs. of water per pound of gas-coke. They had a letter from a user giving the figures for a test with bad roads just before the frost came. He said:—"We take a 6-ton load from Darwen to Manchester, and a 6-ton load back on 5 cwt. of coke and about 350 gallons of water. Of course we include the lighting-up of the fire. The mileage run is about 45 per day, and we have a very heavy pull from Darwen to Bolton, an average rise of 1 in 30 for 3¼ miles, and in one part 1 in 20 for 700 yards on very soft moor road." They thought the figures of running-costs of steam-wagons too high, and that £55 was enough for depreciation, £13 for insurance, £10 for rent, and £125 for wages. Mr. Brodie put the life of their wagons at 10 years, and these were old ones. At any rate, it would be quite safe to estimate the life as 7½ years.

Mr. Sheffield.

Mr. G. H. SHEFFIELD thought it would have proved interesting if the Author had enlarged upon the construction of the chassis of motor-vehicles, more particularly with reference to the bodies and chassis of public vehicles, such as omnibuses. It appeared that a great deal of attention had rightly been devoted to perfecting a number of internal-combustion engines and driving-gears, but the

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chassis had, in the majority of cases, been looked upon as a necessary nuisance, merely devised, or modified, to carry the propelling portion of the structure, without any close attention being devoted to analysing its correct functions. He investigated the working of motor-omnibuses some time ago, and was impressed with the lack of rigidity in the chassis or underframe. He formed the opinion that the connections between the engine-frame and the main frame were defective in design and incapable of maintaining a true alignment, due to want of transverse stability, and that there was not sufficient anchorage to resist the fore-and-aft racking moments set up by the gear-thrust; consequently, the bed-plates of the engines worked loose upon the frames and undoubtedly contributed to the noisiness of the gear. Instances had come under his observation of the main shaft being slung at the back of the gear-box, from a light cross connection 4 inches deep, attached at each end to the main frame by side brackets, each with only a single row of rivets, all in line. Of course these rivets never remained tight through the bending of the cross bearer and faulty attachment. The abrupt setting in of the frames, without reinforcement, to permit of more room for the play of the steering-wheels, combined with want of resistance to bending and twisting moments, proved a fruitful source of distortion and, eventually, fracture at the point of the setting in of the frames. After completing his investigations, Mr. Sheffield came to the conclusion that it was a mistake to mount a separate body —which was a mere enlargement of the old horse-omnibus, held together by a series of mortised joints, half a dozen iron straps and a quart or two of glue—upon a basket-like structure consisting of a shallow chassis or underframe, subject to the racking moments of geared machinery, and in which the ratio of depth to span was out of all proportion to the load carried, and caused stresses to come upon the body which it was never designed to accommodate. Acting upon the invitation of the Brush Electrical Engineering Company, he had considered the possibilities of producing an all-steel motor-omnibus which would be free from many of the defects in existing structures. The points in view were: a limited increase, if any, in the weight, a commercial structure involving the use of standard sections only, and freedom from risk of fire. To ensure smooth running and steady maintenance of the gearing in true alignment, which was absolutely necessary for noiseless working, and for reduction of frictional losses, a rigid framing well braced in every direction was the first essential. Inequalities in the road should be accommodated by the bearing-springs and in their connections to the frame. The outcome of Mr.

Mr. Sheffield.

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Mr. Sheffield. Sheffield's deliberations was a design[1] in which the curved sides, together with the top bracing, formed a complete structure. The side stanchions, carrying the roof-load in conjunction with the end diaphragms, were framed into the main longitudinals, or bottom sills, which were suitably arranged to take the necessary complement of springs and axle-guards. A steel bulkhead, or diaphragm, behind the driver's seat, isolated the interior of the vehicle from any possible contact with the petrol-supply. This bulkhead was reinforced to take up any web-stresses. There was a similar diaphragm at the back end of the vehicle, with the centre portion cut out and framed by a continuous angle forming the doorway. Longitudinal stretchers, which were utilized for the seats, were framed in between the back and front bulkheads, and were stayed at intermediate points from the curved side stanchions. Ample facilities were provided for getting at the gear-box and the live-axle. The increasing demand for higher power, and the general introduction of motor-vehicles for carrying goods and produce, called for the use of steel in the construction of the bodies, in preference to mortised and bolted timber with its attendant weakness.

The Author. The AUTHOR, in reply, disagreed with Mr. Aveling's statement that chains were liable to stretch and break. Modern chains neither broke nor stretched. The term stretching was often applied incorrectly to the lengthening of chains caused by wear. Modern chains sometimes wore badly owing to their being incorrectly placed and unprotected. Again, with regard to Mr. Aveling's statement that the motor-wagon illustrated in Figs. 8, Plate 2, could not be economical, as a simple engine was shown, here again experience was against Mr. Aveling, as the Author had explained. Mr. D. J. Smith in the discussion had also shown that the use of highly superheated steam made for high economy even when simple engines were used, and it was doubtful whether the compounding of wagons using steam of high temperature was worth the additional complication involved. As stated in the Paper, the Author was fully aware of the heavy debt that the designers of modern commercial vehicles owed to traction-engine designers who, through long experience, had elaborated a type of engine whose good points had been too much neglected by motor-wagon designers. This was being rapidly remedied, but in the matter of the use of chains instead of gearing the wagon-designer had had the great advantage of being able to use chains turned out by such makers as

[1] British Patent No. 19,807 of 1906. See also *Engineering*, vol. lxxxiii (1907), p. 348.

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Mr. Hans Renold by automatic machinery, which, as regarded strength, durability, and efficiency of transmission, were greatly in advance of the older form of chains or of any form of gearing, so that the best designs of modern motor-wagons were chain-driven, of the type shown in Figs. 8. Mr. Calvert had raised an interesting point in challenging the Author's assertion that there was less necessity for change of gear in steam-driven than in petrol-driven vehicles. If a motor-vehicle required a range, in the forces applied to the driving-wheels, of 1 to 20, this could easily be given in the steam-engine, using the instantaneous flash or semi-flash generator, by varying the generator-pressure from 30 lbs. up to 600 lbs. per square inch. In the case of the internal-combustion engine the range of variation possible in the mean effective pressure in the cylinder could not be more than 1 to 2—say, from 40 lbs. per square inch as a minimum to 90 lbs. as a maximum; hence the necessity for change of gear-ratios. Mr. Calvert might have seen this from the steam-wagon illustrated in Figs. 8, Plate 2, which had no change-gear and yet was found in practice to haul its load over the extreme variations of road-surface and gradients that were met with in ordinary commercial uses. Mr. Cornock was mistaken in thinking that the working-costs shown in the Tables were based on estimates. In only one case had some estimated figures been added to render them comparable with others. The whole of the figures had been obtained from users and might be taken as illustrative of actual experience. This accounted for the discrepancies mentioned by Mr. Cornock, which always arose when actual figures were brought into comparison. Referring to his remark on the tractor in Figs. 10, Plate 3, the Author had not overlooked the fact as to the shoeing of the driving-wheels, but Mr. Cornock was mistaken in supposing the Act required the wheels to be smooth-shod. The difference between the regulations for heavy motor-cars and for traction-engines lay in the spacing of the cross strips. Mr. Cozens-Hardy had called attention to certain discrepancies which he asserted existed in the comparisons made in the Paper, in the consumption of fuel in the modern steam-driven car-engines as compared with those which were petrol-driven. The explanation was this. The Author did not deny that if in both cases the brake horse-power were measured at the fly-wheel a very large economy would be shown by the petrol-engine; but the case was widely different if the power was measured at the periphery of the driving-wheels. The mechanical efficiency of the transmission-gear used in the steam-cars appeared to be so greatly in excess of that used in the petrol-cars that it probably accounted for the fact that Lord Russell had noticed that the fuel-consumption of two cars of equal power, one petrol-

The Author.

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The Author. driven and the other steam-driven, both using the same quality of fuel, was slightly in favour of steam. This experience of Lord Russell's therefore more than justified the Author's statement that the average fuel-consumption of modern steam-cars might be taken as only 15 per cent. in excess of that of the petrol-driven cars for equal work done. Mr. Cozens-Hardy's notes on the power exerted by horses drawing coaches were very interesting, and formed a valuable addition to the discussion. The Author noted with pleasure the remarks made by the Lancashire Steam Motor Company which largely corroborated his own views and experience. He agreed with them in their remarks as to the disadvantage of the live axle on wagons fitted with rubber tires. Traction-engine builders, however, were able by the use of driving-wheels of large diameter to use live axles in a satisfactory manner, and their axles were remarkably durable.

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12 and 19 February, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

The discussion upon Colonel R. E. B. Crompton's Paper, "Modern Motor-Vehicles," occupied these evenings.

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26 February, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

(*Paper No. 3696.*)

"On the Limits of Thermal Efficiency in Internal-Combustion Motors."

By DUGALD CLERK, M. Inst. C.E.

THE Institution Committee on the Standards of Efficiency of Internal-Combustion Engines have recommended that the standard engine of comparison should satisfy the following conditions:—

(1) The reception and rejection of heat should take place as nearly as may be in the same way as in the actual engine.

(2) There should be no heat-losses due to conduction, radiation, leakage, or imperfect combustion.

(3) The data for the numerical evaluation of the standard should be ascertainable by simple measurements.

(4) The expression for the efficiency of the standard should be a simple one.

Also, that the standard working-fluid to operate in the engine be air, which is to be assumed as obeying perfectly the laws of gases. The specific heat is to be assumed as constant for all working-temperatures, and the value of γ, the ratio of specific heats at constant pressure and at constant volume, is to be taken as 1·4.

With engines working on the constant-volume cycle, these assumptions result in a very simple method of determining the ideal efficiency of the ordinary four-cycle engine. That ideal efficiency is found without reference to heat-quantities or temperatures. It is determined solely by the ratio of the combustion- or compression-space, to the total enclosed volume behind the piston when it is at its extreme "out" position, and is given by the simple formula—

$$\eta = 1 - \left(\frac{1}{r}\right)^{0\cdot4}$$

where η denotes the efficiency

and $$\frac{1}{r} = \frac{\text{minimum volume}}{\text{maximum volume}}.$$

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The members of the Committee were satisfied that, given the ideal efficiencies of a number of engines calculated in this way, the actual indicated efficiencies obtainable with good gas-engines, adjusted to give their best economy, bore a ratio which varied from 0·5 to 0·7. This appears to be quite clear, from calculations made by the Author from Professor Meyer's experiments upon varying compression-ratios. These experiments were made with an engine having a cylinder 7·8 inches in diameter, and of 11·8 inches stroke, and the compression-space was varied to change the compression throughout a range of 40 lbs. to 80 lbs. per square inch above atmospheric pressure. Table I shows how closely the actual indicated efficiencies follow the air-standard efficiency. The actual efficiency, it will be seen, can be obtained by multiplying the air-standard efficiency by 0·58.

TABLE I.—CALCULATED FROM PROFESSOR MEYER'S EXPERIMENTS.

Actual Efficiency.	Air-Standard Efficiency.	Actual / Standard.	Revolutions per Minute.	Dimensions of Engine, etc.
0·250	0·44	0·58	257	Engine 7·8 inches in diameter by 11·8 inches stroke. Compression varies between 40 lbs. and 80 lbs. per square inch above atmosphere.
0·244	0·42	0·58	249	
0·214	0·37	0·58	251	
0·188	0·33	0·57	225	

This is clearly shown also by Table II, calculated by the Author from Professor Burstall's experiments.

TABLE II.—CALCULATED FROM PROFESSOR BURSTALL'S EXPERIMENTS.

	Actual Efficiency.	Air-Standard Efficiency.	Actual / Standard.	Maximum Temperature.	Dimensions of Engine, etc.
		First.			6 inches in diameter by 12 inches stroke. About 200 revolutions per minute. Compression 30 lbs. to 105 lbs. per square inch.
A^7	0·189	0·33	0·57	1145° C.	
B^8	0·212	0·36	0·59	1098° C.	
C^7	0·219	0·43	0·51	1154° C.	
D^8	0·231	0·47	0·50	1094° C.	
		Second.			
A^1	0·166	0·33	0·50	1751° C.	
B^2	0·187	0·36	0·52	1745° C.	
C^1	0·172	0·43	0·40	1749° C.	
D^1	0·181	0·47	0·38	1437° C.	

Here the cylinder was 6 inches in diameter, and the stroke 12

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inches, and the compression-pressure varied from 30 lbs. to 105 lbs. per square inch above atmosphere. Two sets of tests are shown in this Table. In the first set the maximum temperatures of the explosions are about 1,100° C.; in the second they are mostly over 1,700° C. It will be observed that in the first set the ratio varies from 0·5 to 0·59. This change in ratio is easily explained by the increase in the cooling surface introduced by a plug put upon the piston in order to raise the compression for experiments C[7] and D[8]. The greater loss by cooling, due to the added surface, leads at once to increased loss of heat and diminished efficiency. The second set of figures shows the prejudicial effect upon efficiency of too high flame-temperatures.

The close relationship between the air-standard efficiency and the actual indicated best efficiency is also clearly seen from Table I of the James Forrest Lecture delivered by the Author[1] in 1904. Engines tested by many well-known engineers, between 1882 and 1900, show the relative efficiency to vary between 0·48 as a minimum and 0·66 as a maximum. In this Table it will be observed that with two engines of nearly equal ideal efficiency, the National 10-inch cylinder and the Crossley 26-inch cylinder, the ratios were respectively 0·6 and 0·66. The larger cylinder had some advantage.

The Committee considered the correspondence of the air-standard with actual indicated results to be firmly established by these and other tests; but they were not satisfied with the existing knowledge as to the variation of the ratios between the ideal and the actual efficiencies, with varying dimensions of the engines of the same ideal efficiency. It was felt that knowledge was wanting as to the change of ratio, when dealing with engines of widely different dimensions. The Author accordingly arranged to place at the Committee's disposal three gas-engines of exactly the same type, having the same value of $1/r$ and of quite different dimensions. The cylinders of the engines were respectively 5·5 inches, 9 inches, and 14 inches in diameter, and the powers were respectively, 6, 24, and 60 I.HP. All three engines were arranged in one room and supplied with the same gas, and apparatus of the same type was used for testing them. It is needless to describe the engines and testing-room; the Report of the Committee enters fully into all necessary particulars. The tests proved, however, that there was some variation of ratio between the relative efficiencies. Taking the mean mechanical efficiency of the full-load trials as 88 per cent., and calculating the indicated power from the brake power, it was found that the relative efficiencies were respectively 0·61, 0·65 and 0·69. The change

[1] Minutes of Proceedings Inst. C.E., vol. clviii, pp. 282–3.

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of relative efficiency due to change of dimensions was fully proved, and it was clearly shown that by bearing these small changes in mind, the engineer could obtain a close approximation to the best actual indicated efficiency to be expected from any given compression used in a gas-engine between these widely varying limits. The experiments, in fact, clearly proved the great utility of the air standard for the purpose of comparing different engines with different compression-spaces, and predicting the thermal efficiency to be expected from each, assuming the combustion-space to be properly proportioned, and the valve-actions to be properly performed. The experiments also proved in a quite definite way that which had been long believed by gas-engine builders, namely, the small gain in economy which can be attained by a large engine as compared with a small one. It is somewhat surprising to note, however, that between 6 HP. and 60 HP., increase of dimensions gives an advantage of only about 12 per cent.

In recommending the air standard, the Committee were well aware that in proposing air as the standard working-fluid with the properties defined in the Report, they were using a fluid which differed in its properties from the actual working-fluid. If the actual working-fluid had the same properties as the ideal, then the relative-efficiency numbers given above would truly represent the ratio of the heat converted into work to the heat which could have been converted under the ideal conditions. In the small engine, for example, the relative-efficiency number 0·61 would have meant that 0·61 of the heat which the actual working-fluid could have converted into work under ideal conditions was converted into work, and with the large engine the proportion was 0·69. That is, the margin to be worked on for improvement was, in one case, 39 per cent., and in the other case, 31 per cent. It was known from certain investigations that this was not so—in fact, that the possible efficiency of the actual working-fluid under ideal conditions was not so high as the number given by the air standard. Had the properties of the actual working-fluid been known, it would have been possible to calculate ideal efficiencies using the known properties. Enough was known, however, to show that the actual properties of the working-fluid in the engine were by no means simply ascertained, and it was felt better to adopt a standard capable of definite expression, from which the actual best efficiencies could be deduced by a multiplier found experimentally. This multiplier, the relative efficiency, thus includes not only the actual imperfections of the engine-cycle, but the variations between the actual properties of the working-fluid, and those of the ideal air assumed as a standard. In order to determine the actual limits of efficiency, it is necessary to attain to some knowledge of the

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properties of the actual working-fluid. As the experiments by the Committee were unusually full and complete, the Author believed it desirable to examine the whole of the results, to see if any trustworthy deductions could be made as to the limits imposed upon efficiency by the actual properties of the working-fluid. The experiments furnish many numbers which are useful for a consideration of this nature.

In order to arrive at some further knowledge of the properties of the actual working-fluid, the Author has made further experiments upon the large or X engine of the Committee's Report, and he has attempted to determine the heat-quantities and heat-distribution in the actual operations of the cylinder by a new method. This new method has been described by him in a Paper read before the Royal Society.[1]

Dealing first with the numbers found in the Institution Report, Table III shows the full-load heat balance-sheet determined by the experiments as given in the Report.[2]

TABLE III.—HEAT BALANCE-SHEET. FULL LOAD.

Designation of Engine	L	R	X
Exhaust waste	35·3	40·0	39·5
Jacket waste	23·5	29·3	25·0
Radiation	7·6	10·0	7·3
B.HP.	26·7	28·3	29·8
	93·1	107·6	101·6

In these experiments all the quantities were determined by separate methods; for example, as regards the exhaust waste, the whole of the exhaust gases were cooled in a water-jet calorimeter, and the heat obtained from them was measured. The jacket waste was determined by careful experiments on the rise of temperature of measured volumes of water flowing through the jacket. The radiation was determined in such a manner as to include in radiation all the heat lost by friction from the working parts of the engine, as well as radiation, and conduction from the heated surface of the engine water-jacket. The brake horse-power was accurately determined by a rope-brake. It will be observed that in the small engine L the items do not add up to equal the total heat of combustion.

[1] Proceedings of the Royal Society, Series A, vol. lxxvii (1906), p. 500.

[2] Minutes of Proceedings Inst. C.E., vol. clxiii, p. 288. (P. 82 in Reprint of Report sold by Messrs. William Clowes and Sons.)

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There is a deficit of 6·9 per cent., while in the engine R there is an excess of 7·6 per cent. and in the engine X an excess of 1·6 per cent.

In order to reason upon the properties of the working-fluid, it is necessary to know with some accuracy the indicated power of the engine, the exact heat-loss to the cylinder during the working explosion and expansion strokes, and the exact amount of heat existing in the hot gases at the termination of the expansion, which heat is discharged with the exhaust. It is difficult to measure all these quantities accurately, and in the ordinary gas-engine balance-sheet, so often presented, there is a considerable overlapping, so that part of the heat remaining in the hot gases after expansion is complete really finds its way into the water-jacket of the cylinder; thus heat-loss to the water-jacket is generally over-estimated, and this heat again appears in the exhaust loss as calculated from the temperature at the termination of the explosion. Accordingly, when the specific heat of the charge is correctly used, a portion of the heat appears twice in the balance-sheet, so that all balance-sheets so arrived at should over-balance. This was first pointed out in the Judges' Report[1] of the Society of Arts Trials of Motors, 1888–89.

In these experiments by the Committee the difficulty of over-balance is eliminated to a large extent by the use of the exhaust calorimeter, but some heat which ought to appear in the exhaust calorimeter undoubtedly has appeared in the water-jacket item, and so the exhaust loss is under-estimated, and the jacket loss over-estimated. There are several reasons for this. One is that when the exhaust-valve opens, the hot gases discharging round the valve impinge violently upon the water-jacketed metal beneath the valve before their course is turned, and then pass through a water-jacketed space before reaching the water-jacketed passage included in the calorimeter-space. As gases in violent motion impinging against a metal surface lose heat very rapidly, it follows that some of the heat which should appear in the exhaust calorimeter appears in the water-jacket. Further, when the gases in the cylinder have fallen to atmospheric pressure, the cylinder still remains filled with hot gases, often at a temperature of over 1,000° C. During the exhausting stroke of the engine-piston these gases are in contact with the sides of the cylinder, and are flowing through the combustion-space and valves, so that a good deal of remaining heat also passes into the water-jacket. The friction of the piston, too, generates heat, and this heat either flows into the water-jacket, or disappears in radiation and conduction from the piston-bottom to the external atmosphere. This also has to be allowed for. Before

[1] Journal of the Society of Arts, vol. xxxvii, p. 214.

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the balance-sheet thus obtained can be utilized for the purpose of discussing the properties of the working-fluid, it is necessary to adjust it. This can only be done approximately from the data already referred to.

In the balance-sheet Table III, as has been said, the radiation loss includes the friction and engine-resistances. From the brake-tests, which may be taken as determined with substantial accuracy, and from the mechanical efficiencies calculated under Section 12 of the Report, which are taken, as the mean values of methods 1 and 2 respectively, at 0·84, 0·85 and 0·86, it is found that the engine-friction for the three engines, L, R, and X, expressed as a fraction of the total heat-supply, is 5·1, 5, and 4·9 per cent. Deducting these values from radiation:—

Designation of Engine	L	R	X
Radiation	7·6	10·0	7·3
Engine-friction	5·1	5·0	4·9
True radiation	2·5	5·0	2·4

Thus the radiation and conduction from the engines, apart from engine-friction, is 2·5, 5, and 2·4 per cent. respectively. Now assume that the engine-friction is divided equally between the crank-pin and bearings on the one hand, and the piston and cross-head pin on the other, then again:—

Designation of Engine	L	R	X
Heat flowing into jacket from piston friction	2·5	2·5	2·4
Deduct these values from jacket waste above given[1]	21·0	26·8	22·6

Using the values so obtained for jacket waste and true radiation, the following amended balance-sheet is arrived at in terms of indicated horse-power instead of brake horse-power:—

Designation of Engine . . .	L		R		X	
Exhaust waste	35·3		40·0		39·5	
Jacket waste	21·0	23·5	26·8	31·8	22·6	25·0
True radiation	2·5		5·0		2·4	
I.HP.	31·8		33·3		34·7	
	90·6		105·1		99·2	

[1] See Table III.

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In this balance-sheet it may be assumed that the indicated power is correct in all cases, and the deficit and excess among the items of exhaust waste, jacket waste, and radiation, may be distributed *pro rata*, in order to add up to 100. Distributing in this way, the following balance-sheet is obtained:—

Designation of Engine	L	R	X
Exhaust waste	41·0	37·1	39·9
Jacket waste	27·2	29·6	25·4
True radiation			
I.HP.	31·8	33·3	34·7
	100·0	100·0	100·0

Comparing the balance-sheets of engines R and X, the jacket waste and true radiation from the engine R is greater than from engine X. This is as it should be, because the indicated power is less in R than in X, and considering the ideal efficiencies to be the same, it is obvious that increased indicated power could only be given by diminished heat-loss to the enclosing walls. Assuming the indicated horse-power efficiency of both to be 33·3, and assuming the heat-loss to be incurred near the beginning of the stroke, then the difference between the sums of jacket waste and radiation in the two engines should be found by multiplying the difference between the indicated powers by three. Taking

$$\text{I.HP. } 34{\cdot}7 - 33{\cdot}3 = 1{\cdot}4,$$

the jacket waste of the engine R should exceed that of X by

$$1{\cdot}4 \times 3 = 4{\cdot}2.$$

This is found to be exactly the case. Obviously the jacket waste of L is too low. Heat appears to have been lost in some way. Assume, however, the same proportion to hold between engines L and X, then

$$34{\cdot}7 - 31{\cdot}8 = 2{\cdot}9$$

that is, the jacket waste of engine L should exceed that of X by

$$2{\cdot}9 \times 3 = 8{\cdot}7$$
$$25{\cdot}4 + 8{\cdot}7 = 34{\cdot}1$$

The jacket waste of L should be, on this consideration, 34·1. Using these numbers then for a fresh balance-sheet, the following is obtained:—

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Designation of Engine	L	R	X
Exhaust waste	34·1	37·1	39·9
Jacket waste and Radiation . . .	34·1	29·6	25·4
I.HP.	31·8	33·3	34·7
	100·0	100·0	100·0

Here it will be observed that the exhaust waste of L is very nearly the same as that actually determined from the exhaust calorimeter, from which it would appear that the heat which has been lost in some way in the experiments was incurred in the water-jacket. This balance-sheet probably represents more accurately the distribution of heat in the engines, but it still includes an excess of heat to jacket waste and radiation, and too little to exhaust waste, for the reasons already given. There is no way of correcting for this, so far as these calorimeter experiments are concerned. To enable this to be done, it would be necessary to construct an engine in such manner that the exhaust-valve water-jacket was included in the calorimeter water-circulation, and even then, it would be necessary to allow for the loss of heat to the cylinder-walls during the exhaust stroke. This might be done by the use of a Callendar platinum thermometer, if it could be arranged to vary quickly enough to follow the change of temperature from one end of the stroke to the other. Assume, however, for the time being, that this last balance-sheet represents the actual distribution of indicated horse-power and exhaust waste. From this can be calculated the maximum possible efficiency of the working-fluid. Add exhaust waste and indicated horse-power.

Designation of Engine	L	R	X
Exhaust waste	34·1	37·1	39·9
I.HP.	31·8	33·3	34·7
	65·9	70·4	74·6

These numbers, 65·9, 70·4, and 74·6, are the sums of the heat converted into indicated work, and that remaining in the exhaust gases at the end of the working stroke. If it be assumed that in each case the whole of the heat-losses from the gases during the explosion expansion stroke are incurred at the beginning of the stroke, then

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efficiency-values can be obtained by dividing indicated efficiencies by these numbers.

L	R	X
$\frac{31\cdot8}{65\cdot9} = 0\cdot482$	$\frac{33\cdot3}{70\cdot4} = 0\cdot473$	$\frac{34\cdot7}{74\cdot6} = 0\cdot465$

From this it would appear that in the three engines the maximum possible efficiency of the actual working-fluid, on the assumptions made, would be respectively 48·2, 47·3, and 46·5 per cent. The assumption made, however, that the heat to the jacket from the expanding gases is entirely lost at the beginning of the stroke is known to be incorrect, as undoubtedly heat is lost all the way during explosion and expansion. If the proportion of heat lost were known for the different parts of the stroke, then it would be possible to calculate the ideal efficiency of the actual working-fluid from this knowledge, without any other knowledge of the properties of the fluid. If it were known how this heat-loss is divided throughout the stroke, then it would be possible to reconstruct the true adiabatic line in this manner, in such a way as to give approximately correct results.

Before dealing with this, however, it is desirable to see if there be any method of checking the proportion of jacket waste and exhaust waste. This cannot be done from the calorimetric observations of the test; but some notion can be obtained from the study of the indicator-diagram. For this purpose there have been selected the diagrams which give a mean pressure corresponding with the mechanical efficiencies shown to be nearly accurate. The composition of the dry exhaust gases of the full-load trial of the X engine is given in Plate 2 of the Committee's Report[1] (Expt. No. 15).

The composition of the coal-gas used is also given in Table IIA of the Report. From these figures has been calculated the composition of the exhaust gases, including the steam produced by combustion, as given in the following Table :—

Composition by Volume and Weight of Exhaust-Gases from X Engine at 32° F. and 1 Atmosphere.

	Cubic Foot.		Lb. per Cubic Foot.[2]		Lb.
H_2O	0·12	×	0·0502	=	0·00603
CO_2	0·05	×	0·1238	=	0·00619
O	0·08	×	0·0895	=	0·00716
N	0·75	×	0·0786	=	0·05895
	1·00		Wt. of 1 cu. ft.	=	0·07833

0·0783 × 2·41 = 0·189 lb. = weight of charge of 2·41 cubic feet at 32° F. and 1 atmosphere.

[1] Plate 6 in Minutes of Proceedings Inst. C.E., vol. clxiii.

[2] See Table I in the Committee's Report.

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The temperature of the charge is estimated at 663° F. absolute, so that the weight at that temperature is

$$\frac{493}{663} \times 0{\cdot}189 = 0{\cdot}140 \text{ lb.}$$

The temperature-drop from the end of the expansion to the charge-temperature is taken as 1,745° F., and the specific heat of the gases by weight is 0·185. Calculating from this, the heat contained in the exhaust gases is 45·2 B.Th.U. per charge; that is, 194,000 B.Th.U. per hour, or 43·0 per cent. of all the heat of the combustible gases.

The indicator-diagrams referred to are given in Appendix I, which also describes the method adopted for calculating charge-temperature, weight, and terminal temperatures, as here used. This would give the balance-sheet of the X engine as follows:—

Balance-Sheet of X Engine from Indicated Horse-Power, and Heat in Gases at End of Expansion-Line, assuming Constant Specific Heat.

Exhaust waste	43·0
Jacket waste and radiation	22·3
I.HP.	34·7
	100·0

That is, the heat present in the exhaust would according to this be 43·0 instead of 39·9, as deduced from the calorimeter experiments. If, however, the specific heat is higher between the range of exhaust and charge-temperature than it is at atmospheric temperature, this quantity would be greater.

The sum of the exhaust waste and the indicated power is 43·0 + 34·7 = 77·7, and

$$\frac{34{\cdot}7}{77{\cdot}7} = 0{\cdot}447.$$

According to this heat-distribution, therefore, the maximum possible efficiency with the working-fluid is 44·7 per cent.

From this examination, then, it follows that, with the actual properties of the working-fluid as deduced from these balance-sheets, only 44·7 per cent. of the total heat given to the fluid could be utilized, assuming heat-loss to the walls to be entirely suppressed.

With the air having the properties assumed by the Committee, the efficiency would be 49 per cent. The air standard is therefore too high; but further investigation is required before arriving at any well-supported conclusion as to the true value of the ideal efficiency.

The work of the Institution Committee, and the foregoing

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discussion based upon it, will make clear the difficulties to be faced in arriving at the ideal efficiency of the actual working-fluid used, assuming work to be done under the same circumstances as in the ordinary engine, but with no heat-loss to the cylinder, and no valve-losses. Notwithstanding the great labour expended upon the experiments and calculations by the Committee, only a very rough approximation to the truth can be arrived at.

In the James Forrest Lecture of 1904, the Author pointed out that certain properties of the working-fluid could be determined for any given circumstances, by compression in a cylinder combined with measurement of the heat-losses during compression. As the whole of the data of the three engines, L, R, and X, had been accurately determined by the Institution Committee, he deemed it a favourable opportunity to continue the investigation on at least one engine, in order to discover if any fairly accurate knowledge of the actual properties of the working-fluid could be obtained from the engine by the methods broadly indicated in the Forrest Lecture.

In 1884–5 the Author made a number of experiments on the explosion- and cooling-curves obtained with various homogeneous mixtures of gas and air ignited at atmospheric pressure. These experiments were described in a Paper read before The Institution in 1886,[1] although some of the results were given by the Author to the late Professor Fleeming Jenkin to be included in a lecture delivered by him to The Institution in 1884.[2] The experiments showed the rise and fall of temperature for a cylindrical explosion-vessel 7 inches in diameter, 8¼ inches in length, and of 317 cubic inches capacity. Had the specific heats been known, it would have been possible from these curves to determine the rate of heat-loss to the walls of the closed vessel per second of time, from temperature to temperature, assuming also that combustion is completed in a given time. These experiments gave cooling-curves which have proved very useful; and many similar experiments have since been made by other investigators; but such results are applicable in strictness only to a closed vessel. No attempt had been made, so far as the Author was aware, to determine a cooling-curve for a cylinder having in it a moving piston.

Taking the X engine, the largest of the three engines with the smallest heat-loss, the Author determined the cooling-curve of the engine under the ordinary conditions of combustion and expansion

[1] "On the Explosion of Homogeneous Gaseous Mixtures," Minutes of Proceedings Inst. C.E., vol. lxxxv, p. 1.

[2] "Gas- and Caloric-Engines." Lecture delivered at The Inst. C.E., 21 February, 1884.

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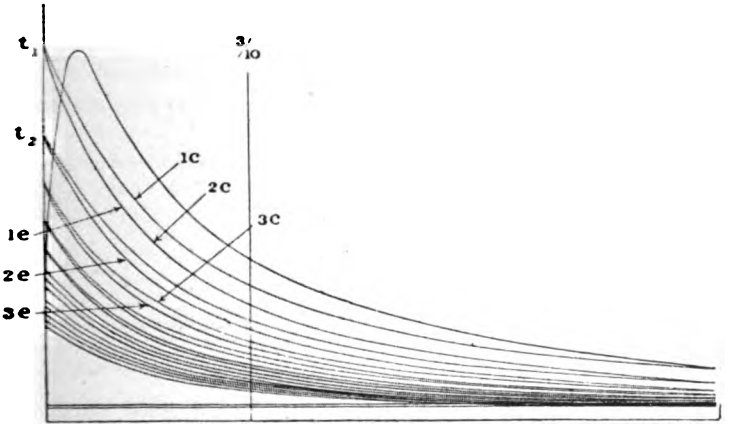
in the working cylinder, in the following manner. He supplied the exhaust- and inlet-valve levers with long pins, upon which rollers were mounted which engaged with the exhaust- and inlet-valve cams. When each roller was slid to one end of its pin, the cam ran clear of the roller, so that the lever was not lifted. This slipping of the rollers was managed by a spring and trigger arrangement, which need not be here described. By this device it was possible to run the engine at its normal speed, under the usual propelling explosions, and to select at any given moment any particular charge, move the rollers out of the range of the cams immediately the charge entered, and so obtain an explosion and expansion-stroke in the usual manner, with the usual charge. When the exhaust period was approached, however, the exhaust-valve remained shut,

Fig. 1.



and accordingly the highly heated gases were again compressed by the piston to the end of the stroke. The energy of the fly-wheel was sufficient to keep up the rotations of the engine, with but little fall in speed during the period of observation. The piston was thus caused to move to and fro, alternately compressing and expanding the hot gases behind it. An indicator-card was taken of this initial explosion-expansion and series of compressions and re-expansions. Such a card is shown in *Fig. 1.* It will be observed that by this method of experiment, the whole of the highly heated products of combustion of a gaseous charge are submitted to alternate compression and expansion within the engine-cylinder while cooling proceeds, and the indicator draws lines showing alternately the rise of pressure and temperature due to compression,

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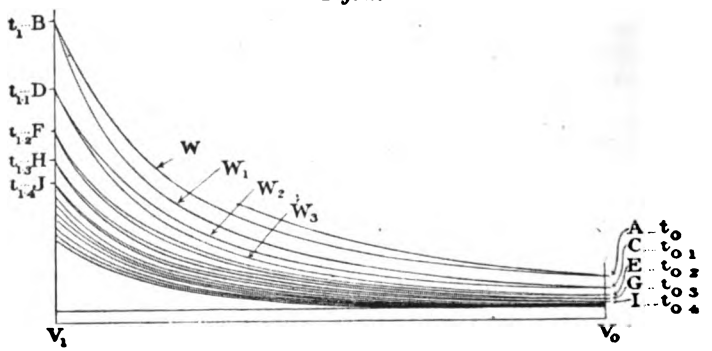
and the fall of temperature and pressure due to expansion. At the "in" end of each stroke the pressure reached becomes less and less as the cooling proceeds. In *Fig. 1* six points of contact are defined before the pressure falls to the ordinary compression-pressure, as indicated by the compression-line. These points, when properly dealt with, furnish a cooling-curve showing the rate at which the gases in the cylinder are cooling, revolution after revolution of the engine. The temperature falls are shown more clearly in *Fig. 2*. Here the first point, that of the completion of the first compression after the working expansion-stroke, is marked B; next D, F, H and J. Obviously, if no cooling took place in the cylinder there would be no fall between the points B and D. The fall, however, is not entirely due to cooling. When the engine-piston expands the gases from B to C, and compresses from C to D, a portion of heat

Fig. 2.



has disappeared through the enclosing walls, but some work has also been done, as shown by the area BCD. Knowing the specific heat of the gases for a temperature fall B to D, the actual heat-loss can be calculated by deducting from the total heat-energy of the temperature-fall, the heat-equivalent of the work-area BCD. It is obvious that if a compression- or expansion-line be drawn, such as CD or DE, and there be no loss of heat on either line, then the specific heat of the contents of the cylinder can be at once calculated from the number of foot-pounds of work causing a certain temperature-rise or temperature-fall. If the specific heat be unknown, the heat-loss and the specific heat can be deduced from such a diagram as *Fig. 2* by a somewhat complicated process of calculation, which need not be entered into here.

Broadly, however, it will be evident that on the expansion-line BC the drop of temperature from B to C is due to two causes; the total

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work done by the expanding gases represented by the area BCV_0V_1 and the flow of heat to the enclosing walls. If the flow of heat can be determined by the aid of cooling-curves, then the mean apparent specific heat of the gases can be determined because the temperature-fall due to work performed will be known.

The Author has determined this apparent specific heat by calculation from mean values obtained from twenty-one separate indicator-cards. *Fig. 3* gives a curve showing the apparent specific-heat values so obtained between temperatures of 250° C. and 1,500° C. The highest temperature measured for the purpose of the curve was 1,450° C. and the lowest 250° C.

The points marked *a*, *b*, *c*, *d*, *e*, *f*, and *g* indicate the experimental values, and each point is the mean of corresponding points on twenty-one indicator-cards. The temperatures and the specific-heat values are given on both Fahrenheit and Centigrade scales. The curve has been prolonged downwards to 70° C., and upwards to 1,500° C.

The mean composition by volume of the working-fluid, calculated from analyses of the coal-gas used at the works, was—

	Volumes.
Steam (assumed gaseous)	11·9
Carbon dioxide	5·2
Oxygen	7·9
Nitrogen	75·0
	100·0

This is practically the same analysis as that given at p. 130, deduced from the Committee's tests on the same engine. In the twenty-one experiments made, however, the mixture varied slightly between the extreme compositions of 1 of gas to 9·8 of air, and 1 of gas to 8·5 of air. This analysis therefore corresponds to an intermediate composition between the two extremes.

Table IV shows the apparent instantaneous specific heats at different temperatures taken from the curve, and Table V gives the mean apparent specific heats for temperature ranges from 0° C. up to 1,500° C. From these numbers it is evident that the apparent specific heat of the working-fluid, consisting of products of combustion in the cylinder of the X engine increases considerably with temperature, so that at 1,000° C. the value is 28 per cent. greater than it is at 100° C., while at 1,500° C. the increase amounts to 31 per cent. The mean apparent specific heat between 0° and 1,000° is 24·1 foot-lbs. per cubic foot, or 15 per cent. greater than at 100°, while at 1,500° C. the increase amounts to over 20 per cent. Inspection

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TABLE IV, FROM *Fig. 3*.—TABLE OF APPARENT SPECIFIC HEATS (INSTANTANEOUS) IN FOOT-LBS. PER CUBIC FOOT OF WORKING-FLUID AT 0° C. AND 760 MILLIMETRES.

Temperature.	Specific Heat at Constant Volume.	Temperature.	Specific Heat at Constant Volume.	Temperature.	Specific Heat at Constant Volume.
°C.	Foot-Lbs.	°C.	Foot-Lbs.	°C.	Foot-Lbs.
0	19·6	600	25·2	1,200	27·2
100	20·9	700	25·7	1,300	27·3
200	22·0	800	26·2	1,400	27·35
300	23·0	900	26·6	1,500	27·45
400	23·9	1,000	26·8	..	..
500	24·8	1,100	27·0	..	..

TABLE V, FROM *Fig. 3*.—TABLE OF MEAN APPARENT SPECIFIC HEATS IN FOOT-LBS. PER CUBIC FOOT OF WORKING-FLUID AT 0° C. AND 760 MILLIMETRES.

Temperature.	Specific Heat at Constant Volume.	Temperature.	Specific Heat at Constant Volume.	Temperature.	Specific Heat at Constant Volume.
°C.	Foot-Lbs.	°C.	Foot-Lbs.	°C.	Foot-Lbs.
0	..	600	22·8	1,200	24·6
100	20·3	700	23·2	1,300	24·8
200	20·9	800	23·6	1,400	25·0
300	21·4	900	23·9	1,500	25·2
400	21·9	1,000	24·1	..	..
500	22·4	1,100	24·4	..	..

of *Fig. 3* shows at once that while apparent specific heat increases more rapidly at first, it tends to a limit at the upper temperatures, so that from 1,200° to 1,500° C. the increase is less than half that from 900° to 1,200° C. The appearance of the curve would suggest a limit for the specific heat-value at no great further increase in temperature.

It will be noted that the term "apparent specific heat" has been used. This has been done because many of the facts discovered by the experiments are inconsistent with the assumption that the change is entirely due to specific-heat change. For the purpose of this discussion, however, it is unnecessary to enter upon this question at all. It is a very complicated one, which has baffled physicists for at least 30 years, and a solution has not yet come. The method of experimenting here described will undoubtedly increase knowledge upon the subject in such a way as to enable the true specific heats to be determined, as well as the apparent

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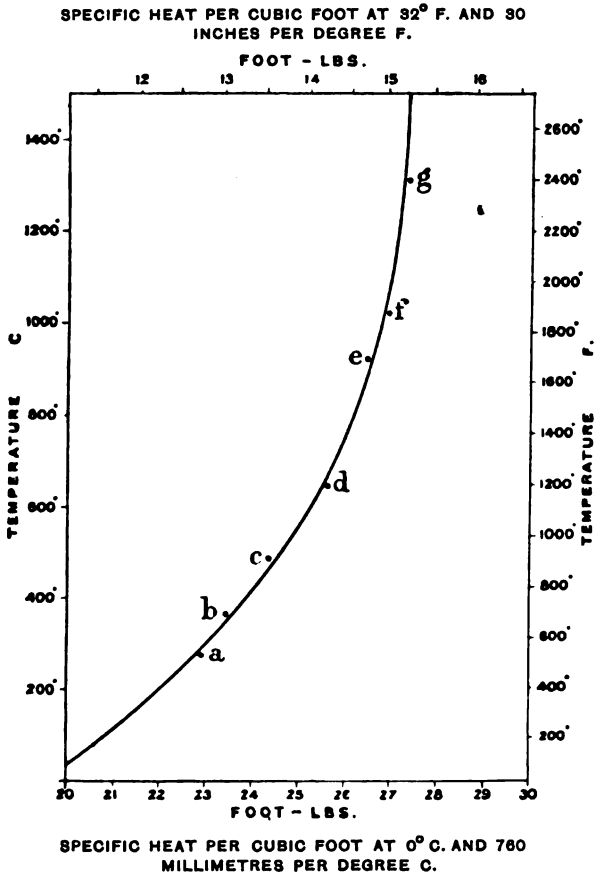
specific heats. So far as the engineer is concerned, however, these apparent specific-heat values may be taken as a closer approximation to the truth than has been previously attained, and numbers calculated as if they were real specific heats are believed to be very

Fig. 3.



nearly accurate. In order to apply the apparent specific heats so determined to the discussion of the gas-engine diagram, it is necessary to know the heat-loss incurred during the explosion and expansion-stroke by heat-flow from the highly heated gases to the enclosing walls. It is also necessary to determine the total energy of the exhaust gases at the termination of the expansion before the

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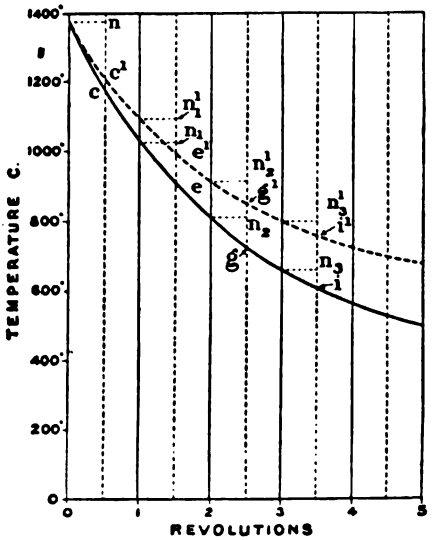
opening of the exhaust-valve. All this can be done from the diagrams shown. *Fig. 4* shows by the full line a temperature-fall curve taken from full-load diagram card No. 22. This curve shows the temperature-fall from about 1,400° C. to 500° C., due to heat-flow through the sides of the cylinder. It shows the temperature fall from temperature to temperature, at each successive revolution. The full line corresponds to observed points such as B, D, F, H, J, *Fig. 2*, including certain work-areas, as well as heat-flow to enclosing walls. The dotted line is a corrected curve giving falls due to heat-flow only, after deduction of work-areas.

Fig. 4.



Before the dotted curve can be applied to determine heat-loss during each revolution or double stroke, it is necessary to calculate from the expansion- and compression-lines of the diagram the total temperature-fall which corresponds to complete double strokes and single strokes for given mean temperatures of expansion- and compression-lines. This has been done, and the curve shown in *Fig. 5* has been prepared. This curve shows the temperature-fall due to any double stroke, at any particular mean temperature within the range of the experiments. From this latter curve,[1] and the apparent specific heat-tables, it is possible to determine the heat-loss to the

[1] To obtain the balance-sheets given a mean curve was taken from the cards 22, 23, and 24.

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cylinder-walls during the explosion and expansion stroke. The mean temperature is determined for any particular expansion- or compression-line by dividing the semicircle into ten equal parts, and measuring the mean temperature within each tenth. As time is the unit, the

Fig. 5.

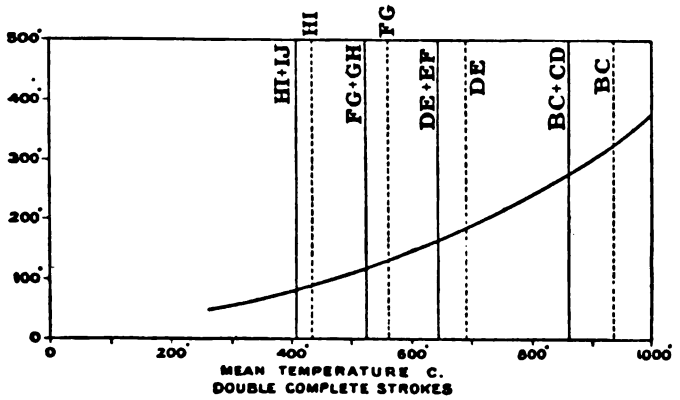

diagram is divided into unequal parts representing equal times. By this method it is possible to calculate the total heat present from a given indicator-diagram. This has been done with Cards Nos. 22, 23, and 24 (*Figs. 6*), for which balance-sheets are shown, as follows:—

Card No. 22.

	Foot-Lbs.	Per Cent.
Heat-flow during explosion and expansion . .	12,480	15·4
Heat contained in gases at end of expansion .	39,800	49·0
Indicated work	28,900	35·6
Total heat . .	81,180	100·0
i.e., 104 B.Th.U.		

Card No. 23.

	Foot-Lbs.	Per Cent.
Heat-flow during explosion and expansion . .	14,000	17·0
Heat contained in gases at end of expansion .	40,500	49·3
Indicated work	27,700	33·7
Total heat . .	82,200	100·0
i.e., 106 B.Th.U.		

Card No. 24.

	Foot-Lbs.	Per Cent.
Heat-flow during explosion and expansion . .	13,100	16·0
Heat contained in gases at end of expansion .	40,600	49·5
Indicated work	28,260	34·5
Total heat . .	81,960	100·0
i.e., 106 B.Th.U.		

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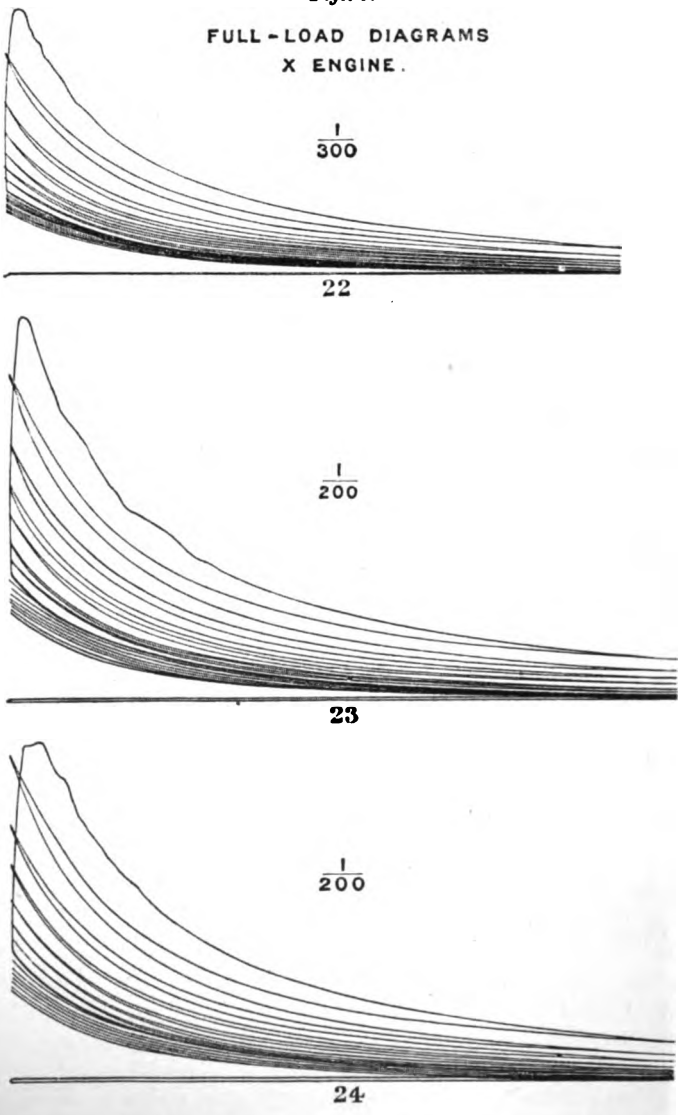
The work and heat quantities have been calculated as foot-pounds.

Figs. 6.



It will be observed that the three diagrams prove the existence in respective experiments of 81,180 foot-lbs., 82,200 foot-lbs., and

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81,960 foot-lbs., corresponding respectively to 104 B.Th.U., 106 B.Th.U., and 106 B.Th.U. These numbers should give the total heat present in the form of inflammable gas.

Measurements by meter and calorimeter show each of these explosions to have as nearly as can be calculated 105 B.Th.U. From this it is evident the experiments have enabled the total heat present to be accounted for without reference to gas-measurement at all.

The mean balance-sheet of these three from cards Nos. 22, 23, and 24 is as follows :—

MEAN BALANCE-SHEET, CARDS NOS. 22, 23, AND 24.

	Per Cent.
Heat-flow during explosion and expansion	16·1
Heat contained in gases at end of expansion	49·3
Indicated work	34·6
	100·0

These indicator-diagrams, together with the apparent specific-heat-flow values, here given, thus enable the total heat evolved in the cylinder per stroke, and its distribution in indicated work, necessary exhaust loss, and heat-flow through the cylinder-walls to be determined from the diagram only.

Compare this balance-sheet with that deduced from the Committee's trials on p. 128.

	Committee's Trials.	New Diagram Trials.
Heat-flow during explosion and expansion	25·4	16·1
Heat contained in gases at end of expansion . . .	39·9	49·3
Indicated work	34·7	34·6
	100·0	100·0

The indicated work is practically the same in both trials and the sum of the other two items is the same also, but the distribution is different. Less heat flows through the cylinder-walls as determined by the Author's new method, and the exhaust gases contain more heat than the Committee's calorimeter trials show. The ordinary trials show 9·3 per cent. too much heat as passing through the cylinder-walls, and practically the same amount too little appears in the exhaust calorimeter. That is, 18·8 per cent. of the total heat remaining in the hot gases at the end of the expansion passes into the cylinder water-jacket during the flow through the exhaust valve upon the first opening and while the piston is making its exhaust

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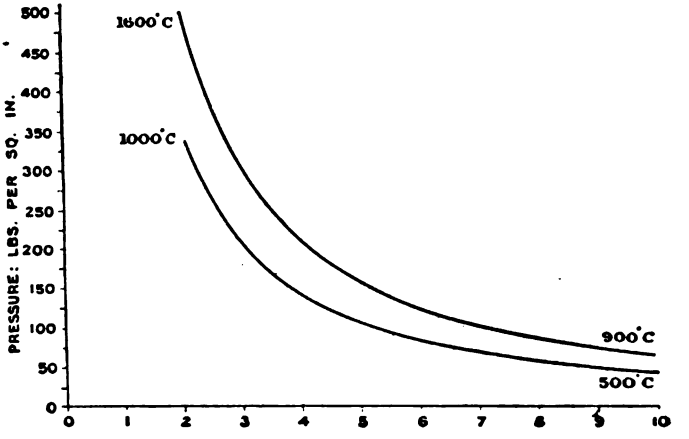
stroke. This seems to be a quite reasonable portion of the total heat, such a portion as experience would lead one to expect.

These new diagram trials afford, in the Author's view, a more accurate heat-distribution balance-sheet than has yet been obtained in any engine, from which can be deduced the ideal efficiency of the working-fluid. Adding together

Heat contained in gases at end of expansion	49·3
Indicated work	34·6
	83·9

Then $\frac{34 \cdot 6}{83 \cdot 9} = 0 \cdot 41$. That is, if this balance-sheet be correct and the heat-loss be assumed as entirely incurred at the beginning of the stroke, then the maximum efficiency of the actual working-fluid for the given compression and expansion is 41 per cent. of the total heat supplied. It is known, however, that the heat is not all lost at

Fig. 7.



the beginning of the stroke; in fact, that the actual expansion-line is lower than the true adiabatic, so that the real value is somewhat lower. A closer approximation may, however, be obtained from the new experiments by calculating the efficiency on the assumption that the apparent specific heat is true specific heat, by constructing[1] the true adiabatic line from *Fig. 3* and Tables IV and V. *Fig. 7* shows this true adiabatic line from temperature 1,600° C. to temperature 500° C.

[1] Appendix II describes the method adopted to draw the true adiabatic for variable specific heats.

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Calculating for these cards again, from this true adiabatic, the ideal efficiency[1] for the actual working-fluid is found to be 39·5 per cent.

From this it appears that the air-standard efficiencies are too high. The actual properties obtained from these experiments only give 39·5 per cent. efficiency, while the air standard gives 49 per cent. As the engine balance-sheet shows 34·7 indicated efficiency $\frac{34 \cdot 7}{39 \cdot 5} = 0 \cdot 878$; that is, the actual engine has converted 88 per cent. of the heat which it possibly could convert into indicated work. This shows that for given expansion the best engines have approached very closely to the theoretical realization of their cycle. The complete suppression of all heat-losses due to conduction, etc., on the explosion expansion strokes could only increase the indicated power from 34·7 to 39·5, that is, improve it by about 13 per cent. This at once explains why so little difference has been found in the economy obtained from large engines as compared with small ones.

In order to check the new method by a test of an entirely different engine, experiments have been made in the Author's laboratory upon a Stockport gas-engine, 6½ inches diameter by 13 inches stroke, giving about 5 HP. The engine is too small, and the heat loss is too large, to enable an accurate determination of specific heat to be made from that engine. The mixture used was slightly different, and the coal-gas was London gas instead of Ashton gas; but the specific-heat values given in Tables I and II are approximately applicable. Calculating from diagrams taken from this engine, and taking the mean of four cards, the following balance-sheet is obtained, calculated in foot-pounds, and reduced to percentages:—

	Foot-Lbs.	Per Cent.
Indicated work	2,690	22·0
Heat lost on explosion and expansion . . .	3,880	31·7
Heat present in gases at exhaust	5,350	43·7
Heat lost on compression	320	2·6
	12,240	100·0
= 15·7 B.Th.U.		

In this balance-sheet the heat-loss is taken from the points AB on four early-ignition cards. In *Figs. 8* A is a reproduction of one of the full-load cards, and B one of the early-ignition cards. The total heat present, as shown by the diagrams, is 15·7 B.Th.U.; the

[1] Appendix III describes the method of calculating ideal efficiency from the true adiabatic.

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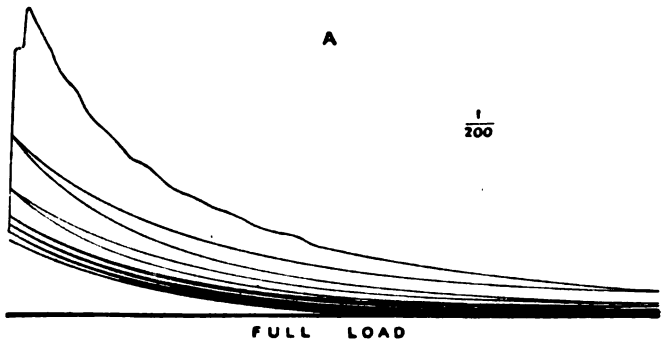
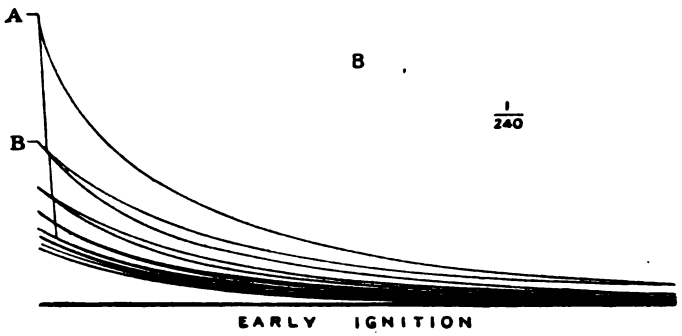
actual heat present, as determined by meter and calorimeter, is 14·5 B.Th.U.

Figs. 8.





An ordinary test made on the same Stockport engine in the Author's laboratory under identical conditions gave the following balance-sheet:—

	Foot-Lbs.	Per Cent.
Indicated work	2,580	21·6
Heat lost to water-jacket	5,920	49·6
Heat given up to exhaust calorimeter . . .	3,440	28·8
= 15·3 B.Th.U.	11,940	100·0

Comparing this with the balance-sheet obtained by the new method:—

	Ordinary Trial.	New Diagram Trial.
Heat-flow during explosion and expansion and compression	49·6	31·7 / 2·6 } 34·3
Heat contained in gases at end of expansion . . .	28·8	43·7
Indicated work	21·6	22·0

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Here again the indicated work is practically the same in two trials, and the sum of the other two items is also very near. The distribution between the two varies as in the trials of the larger X engine, but to a larger extent, a smaller proportion of heat going to the exhaust calorimeter in the smaller engine.

From this it appears to be proved that the apparent specific-heat numbers may be used for determining the approximate heat-distribution in an engine, using the ordinary mixtures of gas and air for maximum economy.

Taking the apparent specific-heat values before given, efficiencies have been calculated corresponding to ratios of $\frac{1}{r}$ varying from $\frac{1}{2}$ to $\frac{1}{7}$.

IDEAL EFFICIENCIES.[1]

(With apparent specific heats given in Table IV.)

Suction temperature = 0° C., γ for compression line = 1·37.

$\frac{1}{r}$	Maximum Temperature 1,600° C.	Maximum Temperature 1,000° C.	Air Standard.
$\frac{1}{2}$	0·195	0·200	0·246
$\frac{1}{3}$	0·286	0·293	0·360
$\frac{1}{4}$	0·354	0·356	0·430
$\frac{1}{5}$	0·384	0·394	0·480
$\frac{1}{7}$	0·439	0·443	0·550

This Table also shows the efficiencies calculated from the air standard. From this it appears that roughly the air standard is about 20 per cent. too high, but within the range of practically applied expansions the air standard follows closely the ideal efficiencies given by the actual working-fluid.

The Author would point out that much knowledge is still required, and many determinations have to be made, before even the apparent specific-heat values can be sufficiently well known for all the various mixtures of inflammable gases used in gas- and petroleum-engines. When these numbers are sufficiently accurately established, each engine can be investigated separately, in order to determine the real efficiency of its working-fluid, and the margin

[1] These efficiencies have been calculated by the methods of successive approximations described under Appendixes II and III.

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remaining for improvement under given conditions. The inquiry, however, is an exceedingly complicated one, which could hardly be undertaken with the time usually at the disposal of the manufacturing engineer.

A great deal of investigation must be performed before the numbers here given can be finally accepted as more than fair approximations. Much work, however, has been done during the last two years, since the Author's James Forrest Lecture, to accumulate data for dealing with this important subject. In addition to the Institution Committee's experiments, and the investigations here described, Professor B. Hopkinson has made some very interesting investigations[1] upon the phenomena of gaseous explosion. Other experiments[2] have been made by Messrs. L. Bairstow and A. D. Alexander, and Professor F. W. Burstall is occupied at the Birmingham University with important experiments upon the large gas-engine, with the same end in view.

Until further knowledge has been accumulated, however, the air standard, as defined in the Committee's Report, furnishes the easiest and best guide to enable the efficiencies of different engines to be predicted or compared; indeed it furnishes a very delicate means of detecting error in design of either combustion-space or valve-proportions, as is clearly shown by the detection of the plug put upon the piston during Professor Burstall's experiments (see Table II, p. 122).

In using this standard, however, it must always be borne in mind, as the Author pointed out[3] as early as 1896, that the actual properties of the working-fluid differ from the ideal air which is accepted as a standard. In that year the Author stated that, allowing for the properties of the actual working-fluid, an actual engine which gave an indicated efficiency of 0·277 could have given only 0·346 had heat-loss been completely suppressed. That is, the actual engine gave 80 per cent. of its possible efficiency, while the air standard for the compression was 0·41, so that the relative efficiency on the air standard was 0·67.

For the purpose of comparison of different engines, this difference introduces no error; but for the purpose of investigation as to the actual limits of efficiency it has to be borne in mind that the

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[1] "Explosions of Coal-Gas and Air." Proceedings of the Royal Society Series A, vol. lxxvii (1906), p. 387.

[2] "Explosions of Mixtures of Coal-Gas and Air in a closed Vessel." *Ibid.*, vol. lxxvi (1905), p. 340.

[3] "Recent Developments in Gas-Engines," Minutes of Proceedings Inst. C.E., vol. cxxiv, pp. 40–41.

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working-fluid can only give lower absolute efficiencies than those determined by the standard. But if γ be taken as 1·285 for the explosion expansion-line, and 1·37 for the compression-line, the change of apparent specific heat between the temperatures of 1,700° and 1,000° C. commonly used in practice is too small to introduce serious error.

The Author has much pleasure in thanking his assistant, Mr. W. Grylls Adams, M.A., for his aid in the laborious work involved in the numerous calculations required for this Paper.

The Paper is accompanied by nine lithographed drawings, from which the Figures in the text have been prepared, and by the following Appendixes.

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APPENDIXES.

APPENDIX I.

In order to find the temperature at any given points on the indicator-diagram, it is necessary to know the temperature at one point on the diagram. When this is obtained, the temperature at all other points can be readily calculated from the volumes and pressures indicated.

The most convenient temperature to determine is the suction-temperature, that is, the temperature of the mixture consisting of exhaust products and fresh charge contained in the cylinder at the end of the suction-stroke. The method adopted for obtaining the suction-temperature for any given speed and jacket-temperature is as follows :—

If v_m be the volume of gas at normal temperature and pressure which has passed into the cylinder, and v_s the volume swept by the piston in a given time, then the charge drawn in is increased in volume in the ratio $\frac{v_s}{v_m}$; the temperature to which the incoming charge of gas and air must have been raised before the inlet valve closed can therefore be calculated.

When the charge is drawn in, there is also a quantity of products of combustion of the previous ignition left in the clearance-space, and this mixes with the fresh charge and further increases its temperature.

It will be seen that the quantity of the total fresh charge drawn in is quite independent of heat given to it by the products of combustion if the specific heats are equal, as any increase of volume of the fresh charge, due to heat given up by the products of combustion in the clearance-space, is compensated for by a corresponding decrease in the volume of the products of combustion. It may therefore be considered that the ultimate suction-temperature is the temperature obtained by mixing the exhaust products in the clearance-space at the temperature they would reach at the end of the suction-stroke if kept adiabatically separate from the incoming charge, with the fresh charge at a temperature which can be calculated from the outside temperature of gas and air when the ratio $\frac{v_s}{v'_m}$ is known.

Taking Test 15, X engine, from the Report of the Committee, 8,449 cubic feet of fluid entered per hour; the temperature of the air was 56·8° F., and the barometric pressure 30 inches. The volume swept by the piston per stroke was 1·961 cubic foot, so that the piston at 165·8 revolutions per minute displaced 9,750 cubic feet of charge per hour. The entering charge therefore increases in temperature from 517·8° F. absolute to

$$517{\cdot}8 \times \frac{9{,}750}{8{,}449} = 597{\cdot}5^\circ \text{ F. absolute.}$$

The temperature of the exhaust gases leaving the R engine was found by Professor Callendar's thermometer to be 800° F., and this temperature is assumed to be

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that of the exhaust gases in the clearance-space of the X engine at the in end of the stroke. The volume of exhaust gases in the clearance-space is 0·448 cubic foot.

The volume of fresh charge at 597·5° F. absolute is 1·963 cubic foot.

Therefore there is in the cylinder, at the end of the suction-stroke, a mixture of fresh charge and exhaust products, whose temperature is that given by mixing 0·448 cubic foot at 800° F., *i.e.*, 1,261° F. absolute, with 1·963 cubic foot at 597·5° F. absolute.

Assuming that the specific weights and specific heats of the fresh charge and exhaust products are equal, then the suction-temperature is :—

$$\frac{1{\cdot}963 + 0{\cdot}448}{\frac{0{\cdot}448}{1{,}261} + \frac{1{\cdot}963}{597{\cdot}5}}$$

= 663° F. absolute; that is, 202° F.

It will be seen that the fraction in this determination which depends on the temperature of exhaust products is small, and, therefore, a comparatively large error in the temperature of the exhaust gases makes little difference in the result.

The diagrams *a*, *b*, and *c*, *Figs. 9*, are reproductions of indicator-cards taken during tests 15, 9, and 2, by the Committee from the three engines X, R, and L, respectively. The cards have been selected as giving the mean pressure, shown by the brake-tests to be accurate. From the above calculation it is known that the temperature of the mixed gases in the cylinder at the end of the suction-stroke is 202° F.; the pressure obtained from the light card taken on the full-load test is 30 inches, and the volume is 1·963 cubic foot. The charge-weight can, therefore, be obtained from the analysis of the exhaust gases as given on p. 130 above.

To obtain from the diagram the heat discharged at exhaust it is only necessary to measure the terminal pressure. This is most conveniently done by continuing the expansion-line from the point where the exhaust valve opens, to meet the ordinate at maximum volume, as shown by the dotted line to the point *e*. The terminal pressure for the X engine, card *a*, is thus shown to be 53·5 lbs.

The absolute temperature at *e* is therefore—

$$\frac{53{\cdot}5}{14{\cdot}7} \times 663 = 2{,}410° \text{ F. absolute.}$$

The temperature drop at exhaust to the temperature of the charge is, therefore, 1,745° F.

The charge-weight may also be calculated from the data given in Tables VII and X of the Report of the Committee. For instance, in Test 15 of the X engine the engine was running 165·8 revolutions per minute.

$$\frac{165{\cdot}8}{2} \times 60 = 4{,}974 \text{ piston-strokes per hour.}$$

Total mixture per hour = 8,449 cubic feet.

Therefore

$$\frac{8{,}449}{4{,}974} = 1{\cdot}698 \text{ cubic feet of mixture per charge.}$$

The explosions per hour were 4,284, and the gas supplied was 785 cubic feet per hour. Therefore

$$\text{Gas per explosion} = \frac{785}{4{,}284} = 0{\cdot}183 \text{ cubic foot.}$$

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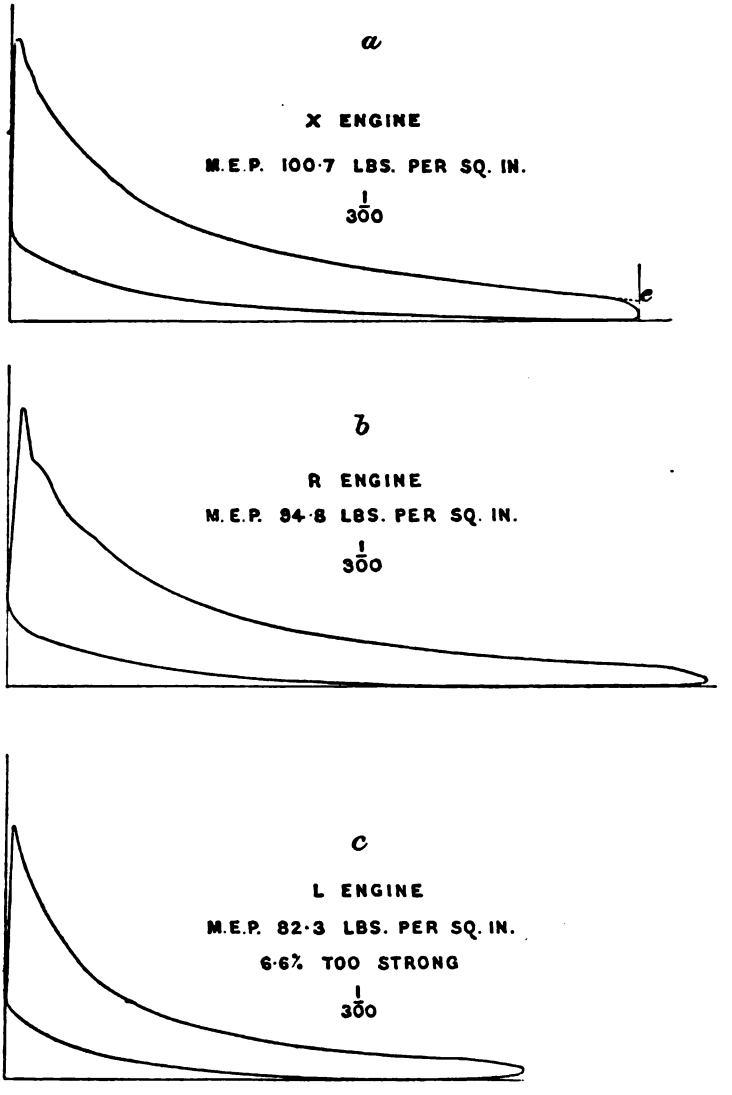
Figs. 9.



Hence $1·698 - 0·183 = 1·515$ = cubic foot of air per explosion stroke.

And air supplied in mixture per hour

$= 1·515 \times 4,284 = 6,490$ cubic feet . . . . . (1)

Total air supplied per hour = 7,664 cubic feet . . . . . (2)

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But weight of dry air per hour . . = 583·7 lbs.
And weight of water vapour per hour = 4·53 „ } Table VII.

588·23 lbs.

∴ Weight of air and water vapour per hour for explosion strokes from (1) and (2)

$$= \frac{6,490}{7,664} \times 588{\cdot}23 = 498{\cdot}0 \text{ lbs.}$$

Weight of 785 cubic feet of gas = 28·9 lbs. per hour.

526·9 lbs.

∴ Weight of entering charge

$$= \frac{526{\cdot}9}{4,284} = 0{\cdot}123 \text{ lbs.}$$

Taking 800° F. as the temperature of the exhaust gases which mix with the entering charge,

Weight of exhaust gases

$$= 0{\cdot}448 \times 0{\cdot}0782 \times \frac{493}{1,261} = 0{\cdot}014.$$

Therefore total charge-weight

$$= 0{\cdot}123 + 0{\cdot}014 \text{ lbs.}$$
$$= 0{\cdot}137 \text{ lbs.}$$

It will be seen that this result agrees closely with that given on p. 130.

APPENDIX II.

Assuming that the apparent specific-heat values given on p. 136 are the true values of the specific heat for the temperature-range, the true adiabatic line between the temperatures given can be determined. This is most conveniently done by calculating the mean values of γ for small temperature ranges, and by using these values of γ to obtain the required curve. The value of γ for a given specific heat, C_v, is readily obtained from the equation where

$$\gamma = 1 + \frac{14{\cdot}7 \times 144}{273\, C_v} = 1 + \frac{7{\cdot}76}{C_v}$$

C_v is the specific heat in foot-lbs. per cubic foot at 0° and 760 millimetres per degree Centigrade.

In order to obtain the adiabatic it is necessary to know approximately the mean temperature on the part of the curve being constructed. It is therefore necessary, in drawing an adiabatic between any two given volumes, say, V_e and V_1, to assume values of γ, and so obtain an approximation to the adiabatic, the temperatures on this approximate adiabatic being then taken in order to select the proper value of γ for the final curve. It is convenient, in constructing the adiabatic, say, between temperatures 1,600° C. to 1,000° C., to divide the volume into a number of parts, say, six, and in the first instance assume that the mean temperature on the curve decreases regularly between the volumes taken. Numbering the ordinates 1, 2, 3, 4, and 5, on the assumptions made, the temperature at V_e is 1,600° C. At ordinate 1 the temperature will be 1,500° C. Therefore, it is required to draw between the volumes V_e and the volume at ordinate 1 the

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adiabatic with a specific heat-value equal to the mean value between the temperatures 1,600° and 1,500° C.

From equation 1 given above, and the specific-heat Table, it is seen that the value of γ for the temperature-range 1,600° to 1,500° C., is

$$1 + \frac{7 \cdot 76}{27 \cdot 5} = 1 \cdot 2825$$

The point where the adiabatic cuts the ordinate 1 can therefore be found from the equation

$$P v^{1 \cdot 2825} = \text{constant.}$$

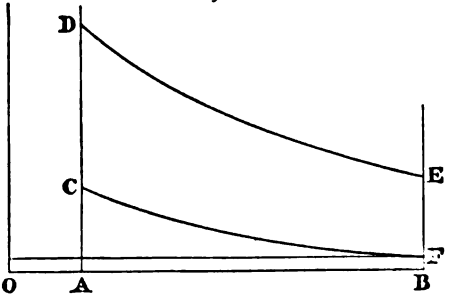
Thus a first approximation is obtained to the adiabatic between the volumes V_e, and volume at ordinate 1. From the pressure at ordinate 1 obtained in this way, the temperature on the adiabatic at 1 can be got, and, if necessary, a further approximation to the value of γ, which should be taken between the volumes considered. The specific-heat changes, however, are not sufficient to make it usually necessary to go further than a single approximation. To get the further point on the adiabatic, the process above described is repeated, taking, as starting-point, the known point on the ordinate at volume 1. Thus the adiabatic can be found for any temperature-range within the temperatures given in the Table of specific heats.

APPENDIX III.

Assuming that the apparent specific-heat values are true specific heats, the ideal efficiency of any engine can readily be calculated.

With varying specific heat, however, the efficiencies will alter as the values of maximum temperature are altered, and it is therefore necessary, in calculating efficiency, to take definite values of maximum temperature, as well as a definite ratio of clearance space to total volume of cylinder. The value of γ for the compression-line may be assumed to be 1·37.

Fig. 10.



In *Fig. 10* let

OA be the clearance-volume,

OB, total cylinder-volume,

D, point of maximum temperature,

DE, adiabatic through D,

FC, compression-line.

Then it is known that the efficiency, η,

$$= \frac{\text{Heat added from C to D} - \text{Heat discharged E to F}}{\text{Heat added from C to D}}$$

$$= \frac{(T_D - T_C)\, C_{v(CD)} - (T_E - T_F)\, C_{v(EF)}}{(T_D - T_C)\, C_{v(CD)}}$$

$$\therefore \eta = 1 - \frac{T_E - T_F}{T_D - T_C} \frac{C_{v(EF)}}{C_{v(CD)}}$$

from which the values of η, given in the Table, can readily be obtained.

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Discussion.

The PRESIDENT, in moving a vote of thanks to the Author for his valuable Paper, observed that he did so with all the more pleasure because about 20 years ago he devoted a good deal of time in an endeavour to work out balance-sheets for gas-engines, but had then only a very small portion of the information that was now at the disposal of engineers owing to the work done by the Author and others during the last 20 years. The President.

Professor W. C. UNWIN considered that the Committee appointed by the Council to consider a standard of efficiency for internal-combustion engines would have been in some difficulty had not the Author offered to place at its disposal a series of engines for testing, and taken the utmost trouble to have those engines fitted with every appliance which the Committee required. The whole of the apparatus, and the services of workmen, were placed at the disposal of the Committee gratuitously by the National Gas-Engine Company, and the members of the Committee were allowed to spend more than a week in the works making the required test. The Institution, and engineers generally, were therefore greatly indebted to the Author and the National Gas-Engine Company for the great trouble and expense incurred by them in affording these facilities. He wished also to acknowledge the services of his colleagues on the Committee who had worked early and late on the experiments. Professor Dalby, Professor Ashcroft, Professor Callendar, Captain Sankey, and the Author had worked very hard indeed at the testing, and Professors Dalby and Ashcroft had spent considerable time afterwards in reducing the large mass of detailed information obtained in the course of the 7 or 8 days' experiments. The Committee had come to the conclusion that for a standard it was necessary to have something rather simple, and they had gone to what was described as the air-engine standard. The Committee was greatly indebted to the Author for the thorough defence he had made in the Paper of the course thus adopted. At the time the Committee began its labours it was known that there was one great difficulty in selecting a standard, a difficulty arising from want of actual knowledge of the variation of specific heat with temperature. It was known that there was a variation, but no engineer was then able to say how much that variation was. The few experiments that had been made by Mr. Le Chatelier and others did not afford a firm basis Prof. Unwin.

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Prof. Unwin. for making any calculation of the probable variation in specific heat. Through work done by the Author and Professor Hopkinson, since the Committee sent in its report, a good deal more was now known, and it was conceivable that if the Committee had now been about to report, instead of having already done so, it might—he did not say that it would—while adopting the same general expression for the ideal efficiency, use a different index from the one adopted, and one that would have brought about a somewhat closer agreement between the standard efficiency and the actual efficiency arrived at by engines. Although the experiments had been made with the greatest care and with exceptional appliances, there were some anomalous results which obviously required readjustment. It had surprised him to find that in experiments so carefully made there might be a difference of something like 12 per cent. in the heat balance-sheet between the best and the worst engine. It showed that in engines made for commercial purposes, and not specially as physical instruments, there were sources of difficulty in making experiments which could not be overcome even by using exceptional care. He thought he might say that the experiments made by the Committee were more complete in several respects than any similar experiments that had been made on gas-engines. The Committee had adopted Professor Hopkinson's plan of measuring the heat in the exhaust gas by a water-calorimeter. Another important point in the experiments was also new. The Committee could not have estimated the exhaust waste without measuring the air supplied to the engine, and that had been measured by a method which had proved to be exceedingly simple and satisfactory, and which he thought had not been used before in the same way. It was of great value that to the Report of the Committee the Author had now added his Paper, because what the Author did not know about working out gas-engine trials was not worth knowing. He had devoted a great deal of attention to making some adjustments in the figures arrived at on probable data, so as to deduce a balance-sheet which was more trustworthy than the direct balance-sheet derived simply from observations at the trial. Although those adjustments looked rather considerable, and although in some respects they were made rather on probable than on certain grounds, he had no doubt the work the Author had done gave a better notion of the distribution of heat in the engine than had been ever given before. He believed the Author was still carrying on the experiments. One of the results of the work of the Committee was the suggestion of a method of determining the variation in specific heat, which was the critical defect in knowledge of the action of the engine.

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Professor B. HOPKINSON found it unnecessary, after Professor Unwin's remarks, to say anything in a general way, and he therefore turned at once to two or three points in the Paper which specially interested him. The first point was the somewhat complicated process of adjustment which the Author had applied to the actual heat-balances obtained by the Committee, and which Professor Hopkinson was not quite able to follow. The Committee's Report apparently differed from the Author, though it might be that Professor Hopkinson's interpretation was wrong. The Author said that in Table III the radiation loss included the friction and engine-resistances, and a little later on he showed that by friction and engine-resistances he meant the whole mechanical losses in the engine, including the pumping-work necessary to draw the gases through the inlet-valves and force them out through the exhaust-valves, and also the piston-friction. The Committee had determined the friction and engine-resistances by measuring the indicated power of the engine running light, and of course the power measured in that way would include the pumping-work and also the piston-friction. The mechanical loss so determined was, he believed, what the Author referred to as friction and engine-resistances in line 5 of p. 127. It would appear, therefore, that the Author considered the radiation-loss, as determined by the Committee, to include pumping and piston-friction. On turning to the Committee's Report it had appeared to him that the radiation loss determined by the Committee did not include pumping and piston-friction. The radiation loss was found in the following manner. The engine was worked at light load without any brake, and a heat-balance was formed exactly in the same way as for a full-load trial, that was, the amount of heat put into the engine was measured from the gas-consumption and its calorific value, and the heat rejected to the exhaust-gas calorimeter and to the jacket-water was also measured. The difference between the heat put into the engine and the heat rejected was taken to be radiation. It appeared to him that radiation so determined could not include piston-friction and pumping-losses, because piston-friction turned into heat, and that heat immediately passed into the jacket, while pumping-losses in the idle strokes went to warm the air that came in; it was warmed as it came in through the inlet-valve and further warmed as it passed through the exhaust-valve. The work done, represented on the indicator-diagram in the bottom loop, really went entirely in warming the gas, and any such heat ultimately appeared in the exhaust-gas calorimeter. Therefore, as far as he could see, the pumping and piston-friction in those tests for radiation appeared in the jacket-

Prof. Hopkinson.

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Prof. Hopkinson.

loss and other loss-items in the no-load balance-sheet, and the unaccounted-for balance (which was taken to be radiation) did not include those two losses. Recent experiments of his own on an engine somewhat similar in size and type to the largest engine tested by the Committee led him to suppose that, of the mechanical losses of such an engine working on the Otto cycle, about 80 per cent. went into the two items of pumping and piston-friction. The radiation would include a certain portion of the friction, the main-bearing friction and the friction of the big end of the connecting-rod, since the heat developed there could not be carried away by the jacket-water or exhaust-gas calorimeter; but that formed a small portion of the whole. It appeared, therefore, that the Author had over-estimated the deduction for radiation which he made in the first Table on p. 127 in order to get what he called the true radiation, namely, the heat that passed out of the engine from the jacket-water, and so on, and was conducted away. He thought that not more than 1 per cent. should be deducted on account of what the Author called engine-friction, instead of about 5 per cent. He would like to hear whether the Author agreed with him that such was the case. Although it had prevented him from following the calculations on pp. 127 and 128, he did not know that in itself it materially affected the ultimate result of the process by which the Author arrived at the first balance-sheet on p. 129. It appeared to him, looking at the third column of that Table, marked X, that it was an adjustment of the original balance-sheet presented by the Committee for the same engine, the substantial effect of which was that while in the Committee's balance-sheet there were three items, brake horse-power, jacket-waste and radiation, and exhaust waste, the Author, with the object, Professor Hopkinson supposed, of exhibiting in the jacket-waste item the heat that had actually passed from the gases into the jacket-water, and not the heat developed by friction in the piston, and so on, had transferred certain items in the Committee's balance-sheet. He had added to the brake horse-power total mechanical losses in the engine, that was, the pumping-loss, the piston-friction, and the small amount of friction in the other bearings. That increased the brake horse-power item and brought it up to 34·7, which the Author called the indicated horse-power. Having added that to the brake horse-power, to get the indicated horse-power, it was necessary, in order to make a balance, to deduct a corresponding amount from the other items in the balance-sheet. The Author deducted the whole amount of what he had added on to the brake horse-power from the jacket-waste and radiation, with, Professor Hopkinson supposed, the object of making that item of jacket-waste represent more accurately the

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heat that had actually passed from the gases into the cylinder-walls. He could quite see that it was proper to deduct from the jacket-waste for that purpose the piston-friction, because the heat thus developed would naturally pass into the jacket-water and be included in the jacket-waste, but he did not see why the Author should deduct from the jacket-waste the pumping-losses, and he would like to hear how he justified deducting the pumping-losses from the jacket-waste in order to adjust the balance-sheet in the manner he had done. A more important point arose, he thought, where the Author investigated the maximum possible efficiency in an engine working with a fluid having the actual properties of the working-fluid, in which all heat-losses were suppressed. It appeared to him that the data the Author had used in his investigation could he conveniently presented by forming a curve, showing the internal energy of the working-fluid in terms of its temperature, and he had placed on the wall a curve (*Fig. 11*) made from the best existing data exhibiting the internal energy. That curve represented the amount of heat in foot-pounds that had to be put into a definite quantity of fluid—the actual fluid used in the Author's experiments—to raise its temperature at constant volume through any range. The quantity of fluid taken was 1 cubic foot at normal temperature and pressure. Starting with a cubic foot of that fluid at 100° C. and heating it, the amount of heat to be put into it to raise it to any given temperature was shown by the full-line curve. The temperature of 100° was chosen as the lower limit because it was convenient and was the temperature at which steam began to condense, so that the latent heat of steam did not affect the curve shown. Below was shown a dotted line representing the internal energy of a cubic foot of air on the same scale. That was a straight line. It was obvious in constructing such a curve that the mean specific-heat values such as the Author had obtained by his experiments would be obtained from the curve by taking the ordinate at any point and dividing it by the abscissa, while the instantaneous specific heat at any point would be given by the slope of the curve at that point. The internal energies at 800°, 1,200° and 1,500°, calculated from the Author's figures for mean specific heat, gave the points ⊙ slightly above the curve. The Paper perhaps gave an impression that the Author's values were more accurate for the purpose of calculation than the values obtained by earlier experimenters. Now, though the Author had determined his specific-heat values by a very ingenious method, differing from all that had preceded it, Professor Hopkinson did not feel quite convinced that they were

Prof. Hopkinson.

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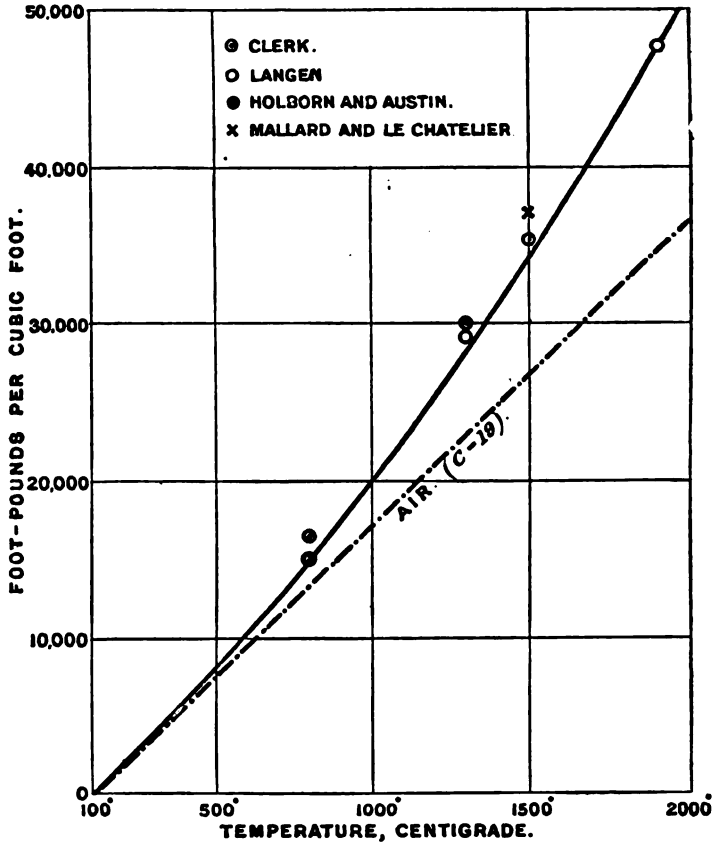
Prof. Hopkinson.

more accurate than the earlier values, hence his curve of internal energy did not quite pass through the points ⊙. He based his curve practically on four points; the lowest point, 100° C., was the origin of the curve. The slope of the curve at that point was also known from the specific heat of the fluid. The method of experimenting used by Messrs. Holborn and Austin[1] (from whose results

Fig. 11.



the point of 800° was calculated) was to heat such gases as carbon dioxide, steam, and air, to 800° C. at constant pressure, and then to pass the stream of heated gas through a calorimeter and measure

[1] L. Holborn and L. W. Austin, "Ueber die spezifische Wärme der Gase in höherer Temperatur." Wissenschaftliche Abhandlungen der Physikalisch-technischen Reichsanstalt, vol. iv (1905), p. 131.

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Prof. Hopkinson.

the amount of heat it gave out in cooling down to some standard temperature. In that way they obtained the internal energy of the gases. Allowance had to be made, of course, for the fact that the heating in that case was at constant pressure, and therefore a certain amount of work was done at the same time. He thought their measurements were entitled to very considerable credit, and that was why he had taken their value for 800° as a point on the internal-energy curve. The two higher points were open to more criticism. They were based on the explosion experiments of Dr. A. Langen[1] made in 1903. The Author had frequently criticized those experiments on the ground that in an explosion it was not possible to be sure that the combustion was complete at the moment of maximum pressure. The method of determining the internal energy from an explosion was simple. A record was taken of the pressure of the explosion, and from the maximum pressure the temperature was deduced; thus the rise of temperature was obtained and the amount of heat put in was, assuming combustion to be complete, equal to the heat of combustion of the gas; so that the internal energy of the gas at the maximum temperature was obtained. The two highest points on the curve had been obtained in that way. An internal-energy curve of that kind could be constructed from the data if the composition of the gas was known,[2] and the curve was not dissimilar from the total-heat curve of steam, the main difference being that in the total heat of

[1] "Untersuchungen über die Drücke, welche bei Explosionen von Wasserstoff und Kohlenoxyd in geschlossenen Gefässen auftreten." Zeitschrift des Vereines deutscher Ingenieure, vol. xlvii (1903), p. 622.

[2] The values given by Messrs. Holborn and Austin for the mean specific heat between 20° and 800° C., expressed in foot-lbs. per cubic foot, at constant volume, are as follows:—

CO_2	35·2
Steam	26·0
Air	19·9

For a mixture of the composition given in the Paper, the mean specific heat up to 800° would be 21·4 according to Messrs. Holborn and Austin's figures; the Author gives 23·6.

According to the formulas given by Dr. Langen, the mean specific heats up to 1,300° and 1,900° respectively, are as follows—

	1,300°.	1,900°.
CO_2	39·8	46·1
Steam	34·5	39·6
Air	22·1	23·5

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Prof. Hopkinson.

steam was included the work done in the water when it expand into steam. Having a curve of that kind, it was a fairly simp matter to work out the ideal efficiency of an engine working with given compression-ratio and gas-charge. The Author gave h method of working out the ideal efficiencies in the Appendix the Paper and to some extent in the Paper itself, and therefo Professor Hopkinson would not deal at any length with th subject, but he would like to show how the efficiency could b worked out directly from a curve of the kind he had exhibite The Author's method of getting the ideal efficiency was really th following. For an engine exhausting at, say, 1,000° C., the Autho worked out, from the specific-heat value at that temperatur the amount of energy that the engine discharged in its exhaust Working backwards from the exhaust end of the expansion-stroke he drew an adiabatic curve, and having that curve of expansion it was possible to construct the whole indicator-diagram and find the efficiency, knowing the amount of heat that was carried away by the exhaust gas, which could be obtained directly from a curve of the kind shown, or such figures as the Author gave. The defect of that method was that it gave an efficiency on a reduced gas-consumption. In the Author's figures on pp. 141 and 142, where he added together the indicated work and the heat contained in the gases at the end of the explosion, the total heat used in the engine was only 83·9 per cent. of what it was in the actual engine. The ideal engine was working as if it used only 83·9 per cent. of the heat supplied to the real engine. It was quite easy, however, to construct an ideal indicator-diagram from an internal-energy curve of the kind he had exhibited, for an engine using any definite amount of gas. He had done that for the three cases of the actual engine, the ideal engine, and the air-engine (*Fig. 12*). Starting at A with a mixture of coal-gas and air used in the actual engine, that was compressed to B, doing a certain amount of work on the gas. The internal energy was greater at B than at A by that amount of work. Then at B the mixture was fired, and the internal energy

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Between these limits the specific heat varies in a linear manner. The range 1,300° to 1,900° represents the limits of Dr. Langen's actual experimental results. At 1,300° the mean specific heat of the mixture, calculated from Dr. Langen's formula, is 24·5 foot-lbs. per cubic foot, whereas the Author gives 24·8. The agreement is remarkably close, having regard to the great difference in the method of measurement, but Dr. Langen's results do not support the Author's suggestion that the specific heat ceases to rise after 1,500° C. Dr. Langen's explosions were in a spherical vessel of large capacity and the correction for loss of heat and for delayed combustion would probably be very small. In this respect his results are much superior to Messrs. Mallard and Le Chatelier's.—B. H.

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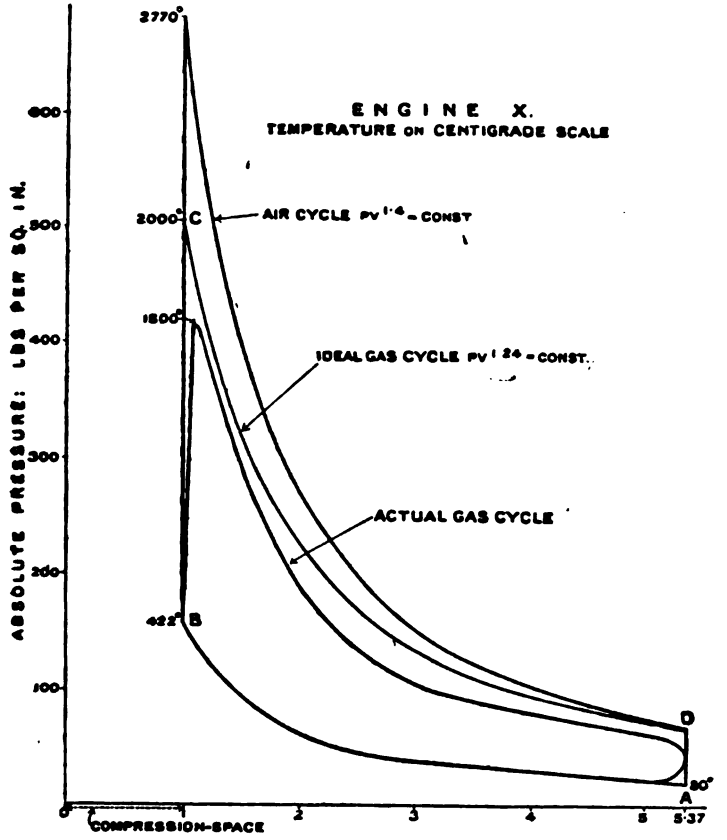
of the gas was increased by the whole heat-value of the gas used, and the point C was reached. The internal energy just after the explosion was known, and from the curve it was possible directly to lay off the temperature. If it was 50,000 lbs. per cubic foot the temperature would be just short of 2,000° C. Then, in the manner

Prof. Hopkinson.

Fig. 12.



shown by the Author, the adiabatic curve was constructed, and thus the ideal indicator-diagram was found.[1] The curves in *Fig. 12*

[1] Take the case of engine X with the following conditions—

Suction-pressure (at A on diagram) = 14·7 lbs. per square inch.
Suction-temperature = 80° C. = 353° Abs.
Cylinder-contents at A are then 1·89 cubic foot.

In adiabatic compression the index may be taken as 1·4, and the absolute

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Prof. Hopkinson.

showed the relation between the work done by the real engine the ideal engine, and the air-engine respectively, when using th same amount of heat.

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temperature at B is then $353 \times (5{\cdot}37)^{0{\cdot}4} = 695$ Abs. The pressure at B i 155 lbs. per square inch absolute. The rise of temperature produced by com pression is therefore 342°, and taking the specific heat as 19 foot-lbs. per cubi foot, the work done in compression is $19 \times 1{\cdot}89 \times 342 = 12{,}100$ foot-lbs. Thi is the internal energy at B. If the calorific value of the gas used is 104½ B.Th.U. as in one of the Author's tests, the internal energy increases on explosion by tha amount, namely, by 81,200 foot-lbs. At C the energy is therefore 93,300 foot-lbs or 51,000 foot-lbs. per standard cubic foot of fluid present, allowing for a con traction of 2 per cent. on combustion. From the internal-energy curve thi corresponds to a temperature of 2,000° C. Thus the point C is found, the pressure there being 506 lbs. per square inch.

The approximate form of the adiabatic curve can be found from the internal-energy curve by a process of trial and error. If it be assumed that the expansion line follows the law $p v^{1{\cdot}24} =$ constant, it will be found that the temperature at D is 1,250° C. The change of energy along the expansion-line C D is that corresponding to a fall of temperature from 2,000° to 1,250° C. and is found from the internal-energy curve to be 44,300 foot-lbs. The work-area under the line C D is 44,500 foot-lbs. Thus the work done in expanding along the assumed line is almost exactly equal to the loss of internal energy. It follows that if the expansion takes place along this line no heat is, on the whole, lost or gained; the loss which takes place in the first part of the expansion being compensated by an equal gain in the second part. The net work after deducting the compression work is 32,400 foot-lbs., and since the heat-supply is 81,200 foot-lbs. the efficiency is 0·399.

The true adiabatic will lie slightly above the assumed line during the first part of its course and slightly below it during the latter part. Thus, with true adiabatic expansion the temperature of the gases at release is slightly lower than it is when the expansion follows the law $p v^{1{\cdot}24} =$ constant, the heat discharged in the exhaust is slightly less, and the efficiency correspondingly greater. But it is easy to show that the efficiency cannot be more than 41 per cent.

The following Table shows the heat-balance for the three cycles, the heat-supply being the same in each. It will be seen that out of 12,500 foot-lbs. saved from the jacket-loss in the ideal gas-engine cycle about one-fourth is converted into work, the remainder being discharged into the exhaust—

	Air.	Ideal Gas.	Real Gas.
Jacket loss	..	..	12,500
Work	40,300	32,400	28,900
Exhaust loss	40,900	49,000	39,900
	81,200	81,400	81,300

B. H.

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Professor H. L. CALLENDAR observed that the Author gave very satisfactory evidence that the air standard which the Committee had adopted was an exceedingly useful standard for the purpose of comparing efficiencies of internal-combustion engines. Some people had complained that since the standard assumed the properties of air, it did not really represent the actual working-fluid in the gas-engine; but from a purely theoretical point of view he did not think that was necessary at all. What was wanted in a standard was something fixed and definite, not something which might have to be varied from time to time according to the latest and best experiments on the properties of the working-fluid; and it was not possible to suit all the different working-fluids. One good fixed standard would do very well for purposes of comparison, provided it represented approximately the kind of variation of efficiency which must necessarily take place according to the theory of the motors. There was one point about the standard which introduced some difficulty, namely, that the compression-ratio was supposed to be known. That was rather a difficult thing to measure in an actual engine, and gave rise to a difficulty in applying the standard. For rough purposes he thought good results could be obtained by simply observing the compression-pressure instead of measuring the compression-ratio. From the compression-pressure it was of course very easy to deduce the effective ratio of the volumes. In applying the standard to ordinary purposes he thought it would be quite worth while to do that. The interesting question raised in the Paper was with regard to the variation of what was called the relative efficiency of the engine. Taking the air standard, the efficiency of the actual engine was compared with the efficiency of the theoretical engine, and the ratio of the two was called the relative efficiency. The Author showed that that varied with the size of the engine from 0·61 to 0·69 in the particular trials, and thence he concluded that, even if the engine was made very large and there was no heat-loss at all to the walls of the cylinders, the improvement could be pushed very little farther. That was an interesting and important result—that there was comparatively so little variation. Another interesting point was the very ingenious method of finding the apparent specific heat under the actual conditions of working in the cylinder. That seemed to be a method of great value, because it measured the thing to be investigated under the actual working-conditions, and the specific heats were obtained directly in foot-pounds of work done by the piston. The only difficulty of the method was the measurement of the indicator-diagrams, and he understood that the Author intended in the near future to improve that greatly by using a more

Prof. Callendar.

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Prof. Callendar. accurate indicator. But, even as far as the Author had gone, he had made a very great advance, and it was not possible sufficiently to admire the ingenuity of the beautiful way in which he had worked out the results. He had found one very interesting result, if it was true—Professor Callendar himself did not feel quite certain about it yet—namely, that the apparent specific heat of the working-fluid in a gas-engine tended to a limit at high temperatures. If that was true it meant that at high temperatures, that was, at the working temperatures on the expansion-stroke, there was practically a constant ratio of the specific heats, and that of course greatly simplified the problem of working out theoretical efficiencies. The value which the Author obtained for the ratio of specific heats at the average working temperatures was 1·285, which meant that the efficiency could be represented by the formula, $1-\left(\frac{1}{r}\right)^{0\cdot285}$. The index was different from that used in the air-standard, but if it was constant the difference mattered very little, and the ratio of the air standard to the working-fluid in the gas-engine remained fairly constant for the ratios used in practice, as the Author showed. His own experiments on the subject, about which he would like to be permitted to say a few words, had led him to agree very closely with the Author's conclusions, and it was satisfactory to find himself agreeing with so high an authority as the Author. He himself had attacked the problem from a totally different point of view, and by quite a different method. The Author had been measuring directly specific heats in a large engine, whereas he himself had attacked the problem from the other side, measuring losses in a small engine. He had chosen the smallest engine he could get, because the losses were all greatly exaggerated and therefore easier to measure. He had made experiments chiefly by the method of taking indicator-diagrams. The engine he had used was a small petrol-motor about 2¼ inches only in diameter; but that did not make a great difference when it was desired to get the law of the loss. He believed he had been the first to get reasonably accurate indicator-diagrams with so small an engine running at a speed of over 2,500 revolutions per minute. In addition, he had placed thermo-couples all over the engine in order to get the temperatures of the walls and investigate the heat-losses there. The experiments were made about 3 years ago, and he had had the honour of exhibiting the results at one of the Institution Conversaziones. He had come to the conclusion that the losses to the walls of an internal-combustion engine could be represented in a very simple manner, namely, that they varied as the ratio of surface to volume of charge under similar conditions, which was just the kind

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of way in which they ought to vary. The loss would be equal to some constant A divided by D, the diameter of the cylinder. Of course the constant A would have different values according to the different conditions of running, but it would not vary very much under ordinary conditions of working. He could not go into all the evidence for that, but he would like to give one or two of the results to show how closely they agreed with the Author's conclusions. Taking the small engine which he used, and the engines L and X of the Author's diagrams, the diameter of his own engine, which he would call C, was $2\frac{1}{3}$ inches, of the L engine $5\frac{1}{2}$ inches, and of the X engine 14 inches, a very wide range. The constant A was approximately unity; if the diameter was measured in inches, A was generally rather larger, but as he had not the exact figure he would take it approximately as 1, because it was easier to calculate. Taking the losses at 1/D, in the small engine they would be 0·43, in the L engine 0·18, and in the X engine 0·07. That was a fraction representing the heat passing through the walls which the engine lost as indicated power. It was not the whole heat-loss to the walls, but the fractional loss representing the loss of indicated power. The fraction which the engine could realize would be $1 - 1/D$. That would be for the small engine 0·57, for the L engine 0·82, and for the X engine 0·93. It was the fraction which the engine realized of the maximum possible for the given working-fluid. The relative efficiency observed for those three engines was respectively, 0·42 for the small engine, 0·61 for the L engine, and 0·69 for the X engine. The two last were the relative efficiencies given by the Committee. It would be seen that in the small engine the losses were enormous, and the relative efficiency was very low; in other words the fraction which it could possibly realize was very small. The relative efficiency observed (0·42) was the fraction 0·57 of the maximum possible, and dividing one by the other he found 0·74 to be the maximum efficiency which the engine could possibly realize if it had no losses at all to the walls during explosion and expansion. The maximum possible would then be for the small engine 0·74, for the L engine 0·75, and for the X engine 0·75. Therefore, if there were no losses, the engines could only realize 0·75 of the air-standard efficiency. With the large engine X, so far as the heat-losses to the walls were concerned, they were getting extremely near the maximum possible; it was nearly a perfect machine, considering the properties of the working-fluid. The matter might be looked at in another way. The maximum possible of 0·75 represented in a way the ratio of the temperature-drop in expansion in the actual engine to the temperature-

Prof. Callendar

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Prof. Callendar. drop in expansion in the ideal engine—the ratio of the efficiency of the actual engine to the ideal engine—and could be represented by taking the corresponding value of the ratio of the specific heats representing the curve. Working out the corresponding value of the ratio of the specific heats he found $\gamma = 1 \cdot 285$, which was also the result obtained by taking the Author's value of the specific heat of the working-fluid at the ordinary temperatures which actually occurred in an engine. That seemed to him to be a very striking agreement, and it also seemed to him that the formula 1/D for the losses which occurred in engines of different sizes was so simple as to be worth using in practice. Just as the efficiency-formula proposed by the Committee took account of the effect of *compression*, so a formula of the kind he proposed could be used as a standard of comparison to take account of the effect of *size*. He hoped to explain the matter more fully at a later date in another place, but he hoped what he had been able to say there would be some slight confirmation of, and some slight tribute to, the beautiful piece of work which the Author had presented to the Institution that evening.

Capt. Sankey. Captain H. RIALL SANKEY remarked that possibly the Paper might be misunderstood to convey the idea that the standard determined by the Committee was no longer satisfactory; but if reference were made to p. 121 it would be seen that paragraphs 1 to 4, which specified the requirements of such a standard, did not in any way refer to the substance, and it was only later on, in the paragraph beginning "Also, that the standard working-fluid," etc., that the air-standard was recommended. He had understood Professor Unwin to say that if the Author's experiments had been forthcoming at the time of the meetings of the Committee possibly an index different from 1·4 might have been adopted for the standard. He hoped he was not breaking any rule in saying that he himself, as a member of the Committee, had advocated a lower index at the time, but he had since come to the conclusion that, until the properties of the substance were really known, it was better to take air for the standard substance, because there could be no doubt in that case that air was being dealt with and not the real substance. When the properties of the working-substance had been fully determined it would be right to modify the standard so as to agree with those properties. He thought that was within sight now. Professor Hopkinson's curve (*Fig. 11*) showed how close was the agreement of the various observations, and he understood that the Author himself was making further experiments: when those were available it would be possible to give rules to calculate what might be called the "actual" standard.

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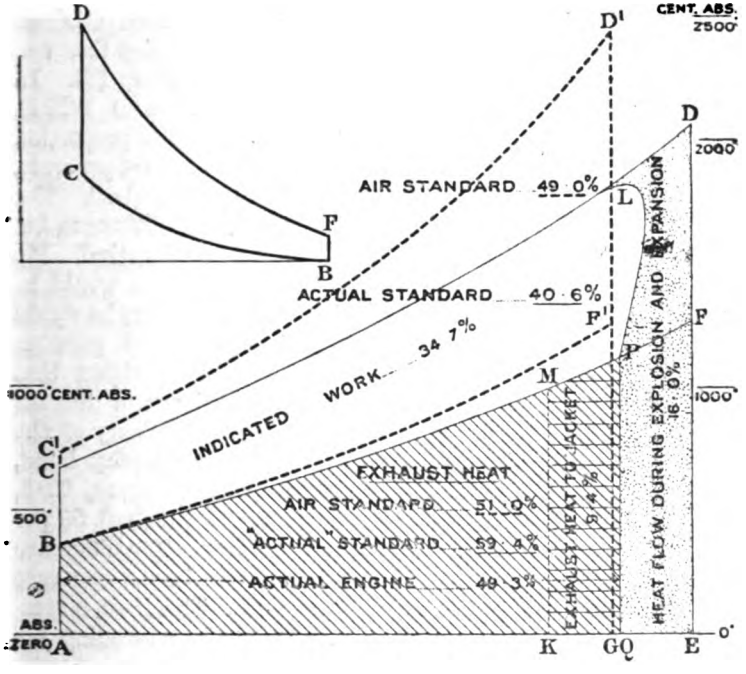
The air standard fulfilled one of the conditions of a standard, namely, it enabled the various actual gas-engines to be placed according to their merit. The Author brought out that point clearly on p. 146, where he said that until further knowledge had been accumulated the air standard as defined in the Committee's report furnished the easiest and best guide to enable the efficiencies of different engines to be predicted or compared. But the air standard did not fulfil another condition of a standard, namely, it did not show how close the actual engine was to perfection. That was Capt. Sankey

Fig. 13.

Fig. 14.



a point he would refer to later, but in the meantime he wished to call attention to a heat-diagram he had prepared to show the differences between the air standard and a standard based on the Author's experiments. The dotted diagram corresponded with the air standard and the full-line diagram with the "actual" standard, as it might be called. In the indicator-diagram (*Fig. 13*) of an ideal engine, B, C, D, and F corresponded to the same letters in the heat-diagram (*Fig. 14*). B was the beginning of the compression; the fluid was compressed adiabatically along B C and exploded at constant

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Capt. Sankey. volume CD; it was expanded adiabatically along DF, and exhausted at constant volume along FB. The area AC′D′G represented the number of heat-units put into the air-standard, and of that number of heat-units the area represented by BC′D′F′ was utilized as indicated work. Therefore the proportion between the area BCD′F′ and the total area AC′D′G was the thermal efficiency of the air standard, and by measuring with a planimeter it was found to be 49 per cent., which was the figure given in the Report of Committee on p. 25 for the "X" engine. Taking the actual substance, and starting the compression at B as before, owing to the increase in the specific heat the point C′ was not reached, but only C at a lower temperature. The constant-volume line CD was a flatter line than C′D′ on account of the increase of specific heat. The expansion-line was adiabatic down to F and then the exhaust took place along FB. In that case the heat converted into work was the area of BCDF. The amount of heat put in was the same as before. The proportion between the area BCDF and the total area ACDE was 40·6 per cent., and this was the thermal efficiency of the "actual" standard. The Author gave 39·5 per cent. He did not think the difference between the two figures 39·5 and 40·6 was merely arithmetical. He could not quite follow the Author's calculations, and he would be very glad to discuss the matter with him; and if necessary he would modify the figure of 40·6.[1] Taking the X engine which gave an indicated thermal efficiency of 34·7 per cent., and dividing that by 49·0 per cent., which was the thermal efficiency of the air standard, 71 per cent. was obtained as the relative efficiency of the X engine compared with the air standard. If, on the other hand, the same figure, 34·7, were divided by the Author's figure, 39·5, for the thermal efficiency according to the actual standard, 88 per cent. was obtained, the figure given in the Paper. The difference between these relative efficiencies and 100 was in the one case 29 per cent., and in the other case 12 per cent. Therefore, a comparison of the engine with the air standard might be misleading, for it would appear that there was still 29 per cent. available, whereas when compared with the true or actual standard it was seen that

[1] Since the Meeting the matter has been discussed with the Author, and it appears that the terminal temperatures assumed by the speaker were different from those taken by the Author for his calculation. After adjusting in this respect exact agreement is arrived at with the Author's figure of 39·5 per cent. as the thermal efficiency of the actual standard.—H.R.S.

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there was only 12 per cent. available for improvement. In the Paper and in the Report of the Internal-Combustion Engine Committee the figure of 71 per cent. was called the relative efficiency. A similar figure in the Report of the Thermal Efficiency Committee for Steam-Engines, and in the Report of the Engine and Boiler-Trials Committee was called the "Efficiency-ratio." It was unfortunate that two different terms had been used to express the same idea, and he ventured to suggest that the Council should take the matter into consideration and see which of those names should be retained. He thought "relative efficiency" was probably the older term of the two, although "efficiency-ratio" had been accepted by the Council previously. He did not think there was much to choose between the names, and he was prepared to maintain that both were good, but he would suggest that "relative efficiency" might be retained when comparing a gas-engine with the air standard, and "efficiency-ratio" should be used when comparison was made with the actual standard. The curved line L P (*Fig. 14*) represented the expansion-line of the actual engine, and the area B C L P was therefore the heat utilized as indicated work by the actual engine. The area A B P Q gave the heat contained in the exhaust gases. Consequently, the remaining area P L D E Q was the heat lost during the explosion and the expansion. This area B C L P had been made equal to 34·7 per cent. of the total heat in conformity with the heat-balance given by the Author at p. 141. On planimetering the other two areas they were found to represent 16·0 per cent. and 49·3 per cent. of the total area. It would thus be seen that these three areas collectively represented, in a graphic manner, the heat-balance given by the Author under the heading "New Diagram Trials" on p. 141. Actually, however, a portion of the heat in the exhaust gases went into the jacket-water, and was shown in *Fig. 14* by the small area K M P Q indicated by the horizontal lines and marked 9·4 per cent. This amount of heat was added to the jacket and deducted from the exhaust heat, increasing the former from 16·0 to 25·4 per cent., and reducing the latter from 49·3 to 39·9 per cent., thus establishing the heat-balance for the X engine given in the Committee's Report, and reproduced by the Author on p. 141. The area B C L P divided by the area B C D F, namely, 34·7/40·6 = 85 per cent., gave the relative efficiency, or "Efficiency-ratio." The various areas referred to above represented the heat-items in the Committee's and in the Author's heat-balances, and he thought that the heat-balances given by the Author at p. 141 might be more clearly stated thus:— Capt. Sankey.

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Capt. Sankey.

	Area in *Fig. 11* by which represented.	Committee's Trials.	New Diagram Trials.
		Per Cent.	Per Cent.
Heat-flow during explosion and expansion .	PLDEQ	..	16·0
„ „ to jacket and radiation	KPLDE	25·4	..
Heat contained in gases at end of expansion .	ABPQ	..	49·3
Heat-flow to exhaust calorimeter	ABMK	39·9	..
Indicated work	BCLP	34·7	34·7
Total	ACDE	100·0	100·0

Mr. Wimperis. Mr. H. E. WIMPERIS observed that if, as appeared from the Paper, a certain amount of change—he might almost say "scrapping"—of old ideas had been rendered necessary, engineers ought not to be unthankful. The "scrapping" suggested by Mr. Dugald Clerk apparently included the old heat-balance table and the constant specific heat. With regard to the former, it was new to him that such large differences as the Author had indicated between the figures on the balance-sheet he now put forward and those put forward by the Committee should be possible. With regard to the constant specific heat, the "scrapping" had not come at all too soon; in fact, in 1903, Mr. Wimperis himself had stated before the British Association that the time appeared to have come for variable specific heats to be employed, and he added that it might be doubted whether any calculations or curves put before the world at that time could be regarded as of value unless, at least, an alternative calculation was given founded on the basis of a variable specific heat. Since that date the evidence favouring the change had grown. He noticed that the Author stated that if the variable specific heat, such as he had found, and which seemed to follow a parabolic law, were adopted, it made calculation extremely laborious, and it could be well understood that was so. He did not know how the parabola would fit the ordinary efficiency-equations, but he thought it would do so very ill. If the straight-line law obtained by Messrs. Mallard and Le Chatelier, and used by Professor Burstall in the experiments he had carried out for the Gas-Engine Research Committee of the Institution of Mechanical Engineers, were employed, a new result could be obtained for the theoretical efficiency. Let the expression for the variable specific heat be $c_v = \beta' + s\,T$, then the efficiency of a constant-volume cycle on a variable-specific-heat hypothesis would be found, neglecting small quantities of the second order, to be

$$\eta_0 = \eta\left\{1 - (1-\eta)\frac{s}{\beta'} \cdot \frac{T_1 + T_0}{2}\right\},$$

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Mr. Wimperis

T_1 being the explosion temperature (absolute), T_0 the compression temperature (absolute), and $\eta = 1 - \left(\frac{1}{r}\right)^{\gamma'-1}$, the familiar form of the efficiency equation. γ' was the ratio of specific heats when T = 0. He had taken the liberty of neglecting one of the Author's experimental points, namely, that at the highest temperature, and putting a straight line through the rest, so that a linear equation for the specific heat could be found. The straight line fell through the other points very well. As a result, taking the case of a one-ninth mixture, it could be shown that, $c_v = 0{\cdot}178 + 0{\cdot}105\,\frac{\theta}{1{,}000}$ (Burstall) and $c_v = 0{\cdot}194 + 0{\cdot}051\,\frac{\theta}{1{,}000}$ (Dugald Clerk), where θ was the temperature Centigrade. Then for $r = 7$, η_0 became 0·43 (Burstall) or 0·46 (Clerk), which agreed well with the Author's figure given on p. 145, namely 0·439. In each case the maximum temperature was taken as 1,600° C., and in the speaker's own formula, a compression temperature of 500° C. was assumed. In the equation above given it was necessary to know the temperatures both of explosion and of compression; in fact, it was the mean of the two, namely, the mean temperature up the vertical line on Professor Hopkinson's diagram. Captain Sankey had spoken of the little discrepancy that now appeared between the recorded measurements of specific heat, but a comparison of the above two formulas showed that there was a considerable difference still. Professor Hopkinson's integrated curve served to mask this fact. A question which he wished to ask the Author was, in what way he considered the rise of specific heat with temperature was connected with dissociation: whether he thought that dissociation could proceed so gradually as to give a linear or even a parabolic law. It had often been supposed, and it was stated in most text-books on the gas-engine, that when dissociation did occur it would do so at fixed temperatures, and instead of giving a uniform slope to the heat-absorption curve would show a broken line. He would like to know the Author's views on that point.

Mr. Bairstow.

Mr. L. BAIRSTOW remarked that in considering the results of the Paper the first thing noticeable was the great difference between the Author's results and those obtained for vessels in which the volume was kept constant. In 1886 the Author published certain results of experiments in which he exploded coal-gas and air in a closed vessel and measured the rise of pressure. In 1904 Mr. Alexander and Mr. Bairstow extended the work to compressed mixtures and found that the same specific heat would hold as for the Author's results. There was also a very comprehensive series of experiments

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Mr. Bairstow. by Messrs. Mallard and Le Chatelier,[1] published in 1883, and although their theoretical considerations were not in agreement with many other results, yet when considered as empirical formulas, they were found by actual trial to agree very well with experiments on coal-gas and air. Taking the specific heat as determined by the Author, extended to 2,000° C., for comparison, the curve as shown on the Author's diagram was of the shape shown in *Fig. 15*. The results given by Messrs. Mallard and Le Chatelier were also shown, the common point with the Author's being at 1,300° C. Within the last 2 years some results had been published for temperatures up to 800° C., Messrs. Holborn and Austin[2] and Messrs. Holborn and Henning,[3] having worked on all the constituents of the coal-gas products. In thinking over the results it seemed to him that the whole differences indicated by the specific heats would be explained if the temperature of the gas varied very considerably from the outside to the centre, and from the Paper he found that the maximum temperature at which the Author began to make measurements was 1,450° C. If no heat had been lost from the gas the maximum temperature would have been 1,980° C., but before the measurements were made the temperature had fallen at least 400° or 500°, and the loss of heat was certainly more than 25 per cent. of the whole. It so happened that the Paper provided an alternative means of calculation for the heat lost during explosion and expansion. Taking the correction from the Author's experiments, he found that the maximum temperature, if there were no loss of heat, would be 1,980° C.; there was some uncertainty about the correction, but it was not very great. If, however, the correction were made for loss of heat only during the first compression-stroke, the maximum temperature was 1,640° C., so that there was a fall of 340° C., due to heat lost through the sides of the cylinder. From the Author's specific-heat curve it would be seen that the mean specific heat corresponding to these temperatures was 28 foot-lbs. per cubic foot, and as the total volume of the gases in the cylinder was 1·795 cubic foot, there was a total loss of energy of 17,100 foot-lbs. In actually performing the first expansion- and compression-strokes a certain amount of work had been done, and the correction for that work amounted to 3,400 foot-lbs., leaving a difference of 13,700

[1] E. Mallard and H. Le Chatelier, "Recherches expérimentales et théoriques sur la combustion des mélanges gazeux explosifs." *Annales des Mines*, 8th series, vol. iv, (1883), p. 274.

[2] See p. 158.

[3] L. Holborn and F. Henning, "Über die spezifische Wärme des überhitzten Wasserdampfes." *Annalen der Physik*, 4th series, vol. xviii (1905), p. 739.

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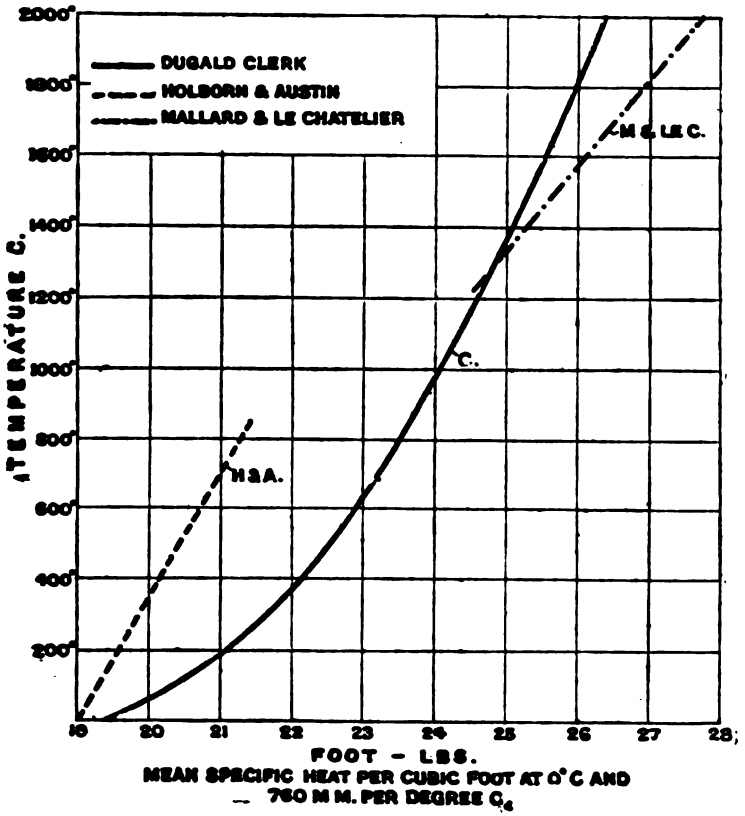
foot-lbs. Reference to the figures for card No. 23 showed that the Author had given 14,000 against the above figure of 13,700, so that that seemed to be the way in which he had made his calculation. The alternative method of calculation was the following:—The energy of the gas in the charge was given in the Paper as 82,200 foot-lbs.; the heat-energy independent of its calorific value amounted to 3,300 Mr. Bairstow.

Fig. 15.



foot-lbs. Besides that, there was the work-area representing energy taken from the fly-wheel during compression, which was 11,600 foot-lbs. The total energy in the gas was therefore 97,100 foot-lbs. That calculation was quite independent of any value of the specific heat. There was a certain loss of heat during the first compression-stroke after explosion and expansion, and calculating from the Author's results, the maximum temperature which

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Mr. Bairstow. would result after deducting this loss was 1,640°. The mean specific heat for 1,640° was 25·4, so that 74,800 foot-lbs. was the total energy in the gas after the heat-losses due to conduction. Besides that, a correction had to be made for the work done, the value of the correction being 3,400 foot-lbs. The total heat in the gas at the end of expansion was therefore 78,200 foot-lbs. The heat in the gas initially was 97,100, and, subtracting the heat left at the end of explosion and expansion, there was a difference of 18,900 foot-lbs. for the cooling loss. There was a considerable difference between the Author's 14,000 foot-lbs., estimated from the specific heat, and that independent method of checking. Instead of coming out at 17 per cent. of the total heat the real percentage was 23·0. If the calculation was correct—and he did not see any reason why it should not be—it meant that the heat in the exhaust gases was over-estimated, because the sum of the two must be constant. On working that out he found that the mean specific heat for the exhaust gases at 1,067° C. was equal to 20·3 foot-lbs. per cubic foot, against the Author's 24·2. Taking the number 97,100 and dividing it by 1,980, the maximum temperature, and by the number of cubic feet of gas in the cylinder, 27·3 was obtained as the mean specific heat of the gases in the cylinder from 0 to 1,980° C. Calculating from Messrs. Mallard and Le Chatelier's results—which agreed with all the constant-volume experiments—the result was 27·7. That agreement was quite satisfactory, and he thought was nearer the truth than the value calculated by the Author. He believed that the whole of the differences were caused by very large variations of temperature in the cylinder, due to the rapid rate of cooling and to the fact that measurements were not begun until a large portion of the heat had left the gases.

The Author. The AUTHOR, in reply, expressed his great indebtedness to Professor Unwin for his kind remarks about the engines tested at the National Gas-Engine Company's works. He had communicated Professor Unwin's appreciation to his brother directors, and all, from the Managing Director and Chief Engineer down to the man who helped to turn the fly-wheel, were very pleased indeed to have had the opportunity and pleasure of working with the Institution Committee. He was glad Professor Unwin had called attention to the point that the air standard, so far, was the only safe standard to take for the purpose of determining efficiency. As was said in the Paper, the air standard enabled one to follow with great minuteness the various losses, comparatively, that occurred in different engines; it showed very clearly the effect even of increasing the cooling surface, and anything wrong was at once indicated. The

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numbers showed that in engines properly constructed, of the highest efficiency, certain results should be obtained. Taking an engine with a certain clearance-space, and taking the formula at the beginning of the Paper and multiplying the result from that formula by some figure between 0·6 and 0·7, the efficiency was found that should be attained in actual practice. If it was found that the figure fell to, say, 0·5, means of improvement had to be looked for, because it was known there was something wrong. It was quite true—and he wished to emphasize it because it was important in relation to the question of the fraction of heat still to be utilized—that in the case of the actual properties of the working-fluid the efficiencies given by the air standard were too high; they bore a certain ratio to the other efficiency which varied as the other efficiency varied, but the absolute ratio was too high. All the speakers in the discussion were agreed upon that point. Accordingly, when the Committee had finished its investigations, he felt that he would like, if possible, to carry the matter a little farther and discover some of the properties of the working-fluid from the actual engine itself; and that had led to the method which he had referred to in the Paper, giving the zigzag diagrams. That method had proved exceedingly useful. A large number of figures could be obtained, and, as no doubt the members had observed, those figures could be manipulated in a great variety of ways. There was considerable room for difference of opinion, and it was not surprising that different speakers should view the subject in different lights. Professor Hopkinson had criticized the adjustment of the balance-sheet in the first part of the Paper. The Author hoped that he had not misled anybody; he had tried to make it quite clear that the adjustment was the best that could be made, that it was only an approximate adjustment. The figures in the first part of the Paper were figures which had been deduced from the actual results of the Committee. He laid some stress upon that part of the Paper so as to show that the balance-sheet, as ordinarily determined, did not represent the true heat-losses and heat-balance from a thermodynamic point of view: that in order to reason from a thermodynamic point of view on the actual efficiencies to be obtained, it was necessary to have a different kind of balance from the ordinary heat-balance so often presented. Professor Unwin proposed the anemometer method of measuring the air, and Professor Dalby proposed the ingenious method of measuring the radiation. In the case of the R engine there was no water running through the jacket at all. There was a very small quantity of water used to get the stream-lines right,

The Author.

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The Author. so as not to have hot water settling in one direction and cold water in another, but there was no water running through in sufficient quantity to affect the whole result. The method consisted in running the engine without load at such a speed as gave the same water-jacket temperature as existed during the tests at full load: that meant that all the heat of explosion that was going through the water-jacket, assuming all the other conditions to be equal, was just equal to the radiation in the experiment where the full load was carried. If while running at light load every part of the external jacket was at the same temperature as in the actual experiments with the full load, then it was assumed that the heat-losses from that jacket represented the radiation-loss actually incurred. In that experiment they carefully measured the amount of heat going into the engine in the form of coal-gas, and then measured the heat of the exhaust in a calorimeter, as used by Professor Hopkinson. The difference between the total heat and the heat going into the calorimeter was the heat-loss by the engine not only in radiation, but in performing the work which was necessary for overcoming much of the mechanical friction. The air-resistance heat, however, reappeared in the calorimeter, because the effect of air-resistance was simply to heat the air, and that heat was partly taken out in the exhaust. Consequently these figures included not only radiation but much of the mechanical resistance of the engine, but only a part of the air-inlet or exhaust-discharge resistances. It was found difficult to compare the three engines and get accurate indicator-diagrams, because, in testing the smaller engine, to take diagrams frequently enough to yield accurate results involved such an interference with the contents of the cylinder as reduced the power and gave false results. The members of the Committee, therefore, had thought it better to determine accurately the brake results only, and then to make a determination of mechanical efficiency and work back to the indicated power of the engine. From that it followed that when he desired to make a balance-sheet including indicated instead of brake horse-power, he had to make a correction that put the resistance of the engine into the balance-sheet. In doing that he had to make the various corrections, which he thought Professor Hopkinson would find, when he had more time to look into them, were in substantial agreement with his own. The Author, for example, had not deducted the pumping-losses from the jacket-waste; he had only deducted his estimated piston-friction, as Professor Hopkinson agreed should be done. He did not think there was much difference between them on the point of the resistance to the fluid

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passing through the valves. On the question of engine-friction, however, the Author could not agree with Professor Hopkinson that 1 per cent. should be deducted from radiation instead of 5 per cent. In determining the mechanical resistances of the engine, so as to get the mechanical efficiency, the Committee had adopted two methods, and the numbers taken by the Author were calculated from the mean values of mechanical efficiency obtained by these methods. In the first method adopted by the Committee, indicated horse-power at no load was added to brake horse-power at full load, the result being the indicated horse-power at full load. In this method of calculation the pumping-losses were included, unless the negative loop on the diagram was subtracted from the positive loop, in the calculation for obtaining the indicated horse-power. In the second method, where the mechanical efficiency was obtained by measurements of the brake horse-power at full load and half load, the pumping-losses were included with the mechanical losses of the engine. In making the correction, part of the loss put down as engine-friction, therefore, might be attributed to pumping-losses, and for this reason the true radiation might be slightly over-estimated. In making the correction, dividing the friction of the engine between the crank-shaft and the cylinder, he took roughly 50 per cent.; he understood Professor Hopkinson said that the connecting-rod end of the crank-pin took up only about 20 per cent. He himself was relying upon experiments made many years ago by Professor Thurston, which showed the division at full load in the engine to be roughly one-half in the piston and its parts and valves, and one-half in the crank-shaft and connecting-rod. If that division were wrong, then the result would be vitiated to a slight extent, but not much. With regard to the method of calculating ideal efficiencies, the values given were obtained by assuming a given maximum temperature for each compression. The quantity of heat added would therefore vary as the compression was varied, and consequently the quantities of gas used would be different. The object of the Table on p. 145 was not to give the efficiency for a given gas-consumption, but to give the efficiencies between limits of temperature commonly used. He would like to have followed Professor Callendar in his very interesting method of determining the efficiency of the working-fluid from a different standpoint altogether. He might say frankly that the results of the Committee depended very largely upon a broad generalization. He had himself been tempted to go in for generalization, but had thought it better to stick to experiment and work out the problem purely

The Author.

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The Author. experimentally. It was surprising and remarkable that, taking the heat-losses and measuring them as Professor Callendar had done, there was no difference in the value of γ. If Professor Callendar had obtained, say, 1·282, he would have looked upon it as confirmation, but to obtain the exact figure seemed almost too good to be true. It should be noticed that the value 1·285 obtained for γ was only intended to apply to the expansion-curve of the gas-engine diagram, and in the ideal efficiencies calculated and given in the Paper the value of the index used for the compression-line was 1·37. Results obtained by using the formula $1-\left(\frac{1}{r}\right)^{1\cdot285}$ would be slightly different from those given. The interesting heat-diagram of Captain Sankey showed only results obtained in a particular case, and until the law of variation of specific heat was definitely known, diagrams of this kind could be used only by making certain assumptions which might or might not be found justified when the true specific heat-values were determined. The balance-sheet given by Captain Sankey at the end of his remarks showed very clearly the true meaning of the numbers found in the balance-sheets according to the Committee's trials, and the new diagram trials. The Author was in agreement with Captain Sankey as to the proposed use of the terms "relative efficiency" and "efficiency ratio." With regard to Mr. Wimperis's formula, based on the experiments of Messrs. Mallard and Le Chatelier, the Author's view was that formulas such as those based on different sets of experiments might be obtained which would differ considerably among themselves. At present the true law of variation of specific heat was not sufficiently known, and he preferred to leave the question of a general formula, applicable to all cases, until the true values were absolutely determined. He would point out that at present there was no proof that the great increase of apparent specific heat was entirely due to change of true specific heat. With reference to Mr. Bairstow's remarks on the different values obtained for the specific heat, when deduced from experiments in closed vessels of constant volume, and from experiments in vessels with moving pistons, calculations had been made by the Author which showed the apparent specific heat as obtained by measurement of the total heat capable of being added by combustion of a given quantity of gas, and of the rise of temperature during explosion, the combustion taking place in the gas-engine cylinder itself. These experiments had always shown higher values of specific heat than those obtained by the method described in the Paper, and it seemed probable that

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the difference was due to the same causes as the difference noticed by Mr. Bairstow. Calculations of specific heat from the total energy of the gas were all based on the assumption that the total heat was evolved before maximum temperature, and in dealing with the explosion expansion-line, and the upper lines of the new diagrams, some error was undoubtedly introduced from this cause. With a properly chosen mixture, and a given speed of the engine, an explosion could be obtained in the engine-cylinder which would give the exact value of apparent specific heat on the explosion expansion-line, found by Messrs. Mallard and Le Chatelier in their closed vessel at constant volume. The method of arriving at the heat-loss to the cylinder-walls during explosion and expansion adopted by the Author was based on the law of heat-loss as found from the curves below the explosion- and expansion-curve, and these curves were much more likely to be free from error due to continued combustion than the explosion expansion-curve itself, and the values were thought to be the best obtainable from the cards dealt with. The difference between the values obtained for the heat-loss on the explosion expansion-line by the two methods described by Mr. Bairstow was due partly to the fact that at the point of maximum temperature combustion was not complete, which would tend to raise the apparent specific-heat value and the heat-loss, when calculating by what might be called the total-energy method; and also to the fact that work done by the gas before maximum temperature was reached was neglected by Mr. Bairstow. In the card considered, this work amounted to upwards of 2,500 foot-lbs. The reason for commencing the measurements with as long an interval as possible after maximum temperature in the Author's experiments was to ensure that the effect of continued combustion should be eliminated as far as possible. The experiments referred to by the President in kindly proposing the vote of thanks would be remembered by The Institution. These experiments were carried out for the Society of Arts in the year 1888, and were really the first important tests of gas-engines. The methods then employed by Sir Alexander Kennedy had been generally followed since. Little progress in the knowledge of the properties of the working-fluid had been made until recently. In the last few years, however, much had been done, and it was not unreasonable to suppose that within a few years the problems connected with the working-fluid in internal-combustion engines would be definitely solved. The Author.

In conclusion, he desired to express his appreciation of the interest shown by the members of The Institution in his Papers.

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The Author. He also wished to express his thanks for the kind manner in which the present Paper had been received by the President and members.

Correspondence.

Prof. Meyer. Professor EUGEN MEYER, of Berlin, remarked that the question raised by the Author as to how much the indicated thermal efficiency could be increased if the jacket-losses during explosion and expansion were suppressed was of great interest to him. The Author had come to the conclusion that the increase in the indicated work could not exceed 13 per cent. Professor Meyer had dealt with the same question,[1] and, although he had approached the matter in a different way, he had arrived at the same result as the Author. As a basis for his investigation he had found that the element of heat-loss dQ transmitted through the walls of the cylinder during the element of time dz was approximately given by the following formula—

$$dQ = c\,S\,(T - T_W)^2\,dz,$$

where S was the surface of the cylinder-walls, T the mean temperature of the gases in the cylinder, T_W the temperature of the walls, and c a constant. He had assumed that T_W was constant; T, however, could be calculated for each point of the stroke from the indicator-diagram. He had thus computed what proportion of the heat lost to the jackets was transmitted through the walls during explosion and expansion, and also in what manner this heat-loss was distributed during expansion in respect of time. The loss in indicated horse-power caused by the heat lost during each element of time was then calculated, and he had found that this loss varied from 12 to 15 per cent. according to the load on the engine; and this was a close approximation to the figure given by the Author, namely 13 per cent. He concurred in the formula given by the Committee for the relative efficiency, namely $\eta = 1 - \left(\frac{1}{r}\right)^{0\cdot4}$, as a means of comparing gas-engines having different degrees of compression represented by r. He had used this formula in his researches[2] on alcohol-motors and

[1] "Untersuchungen am Gasmotor." Zeitschrift des Vereines deutscher Ingenieure, vol. xlvi (1902), p. 945 *et seq.*

[2] "Versuche an Spiritusmotoren und am Diesel-Motor." *Ibid*, vol. xlvii (1903), p. 513 *et seq.*

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on the Diesel motor, and had found that it could be usefully applied to the comparison of alcohol- and benzine-motors. He had used 1·37 as the value of γ instead of 1·4, but the difference due to this alteration was small. Prof. Meyer

The Author, in reply, was much interested in the results calculated from the formula deduced by Professor Meyer in 1902. It was surprising that he was able, 5 years ago, to separate the heat-loss through the walls from the other losses to the jacket with sufficient accuracy to predict so closely the numbers obtained to-day by other modes of investigation. It should be noted, however, that the dimensions of the engines used by Professor Meyer and the Author were widely different, and the coincidence of the determinations was the more notable and gratifying on that account. The Author was gratified to learn that Professor Meyer had found so close a correspondence between the air-standard values for varying compression in engines using fuels so different as alcohol and benzine. The Author.

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5 March, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

The Council reported that they had recently transferred to the class of

Members.

Henry Newmarch Allott.
Andrew George Ashcroft.
Frederick William Bach.
John Ferguson Bell.
Alfred Chorley Cookson.
Thomas Hedges Deakin.
John Llewellyn Holmes.
Frederick Thomas Hopkinson.
Samuel Wright Perrott, B.A.I. (*Dubl.*)
John Archibald Polwhele.
William Llewellyn Preece.
Frederic David Sharp.
John Robert Wignall.

And had admitted as

Students.

Arthur Guelph Banks, B.Eng. (*Liverpool.*)
Reginald Fitzroy Clayton.
William Thomas David, B.Sc. (*Wales.*)
William Meggat Dempster.
Charles Alexander Grant.
John Jerom Hartley, B.Eng. (*Liverpool.*)
Percy Croom Johnson.
Alexander Kinnes, B.Sc. (*St. Andrews.*)
Lawrence Werner Wyld Lees.
George Edward Lines.
Paul Augustus Molloy.
Harry Ralph Ricardo, B.A. (*Cantab.*)
William Bolton Rimmer, B.Sc. (*Victoria*), B.Eng. (*Liverpool.*)
Clifford Ramire Shaddick.
George Wishart.

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The Scrutineers reported that the following Candidates had been duly elected as

Members.

ARTHUR CHAMPAGNÉ WIDENHAM FOSBERY.
WILLIAM GEORGE TOOP GOODMAN.
ANDREW HAMILTON.
GEORGE CAMPBELL MACONCHY.
JAMES MASSIE.
JOSHUA SHAW.
SAMUEL MATTHEWS VAUCLAIN, D.S., (*Penn.*)

Associate Members.

RUSSELL VINCENT ALLIN, Stud. Inst. C.E.
JOHN HOWARD PENNY BRADFORD, Stud. Inst. C.E.
BERNARD DUNELL.
HENRY ARTHUR ROLLESTON EDWARDS, Stud. Inst. C.E.
ROMNEY ROBINSON FARIS, B.A., B.A.I. (*Dubl.*)
CONRAD GRIBBLE, Stud. Inst. C.E.
ALFRED DALE LEWIS, B.A. (*Cantab.*), Stud. Inst. C.E.
CYRIL WALTER LLOYD-JONES, Stud. Inst. C.E.
HENRY FURNEY NOLANS, M.A., B.A.I. (*Dubl.*)
BERTIE REYNOLDS.
FRED THOMAS, M.Sc. (*Victoria.*)
HAROLD WALMSLEY, Stud. Inst. C.E.

Associate.

ALFRED LEONARD LAWLEY.

The discussion upon Mr. Dugald Clerk's Paper "On the Limits of Thermal Efficiency in Internal-Combustion Motors" occupied the evening.

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12 March, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

(*Paper No. 3703.*)

"The Construction of Overhead Electric Transmission-Lines."

By ALEXANDER PELHAM TROTTER, B.A., M. Inst. C.E.

HE would be a rash man who should declare that it is impossible that power will be transmitted in the future without conductors. Meanwhile, conductors must be used, and are placed below ground as insulated cables, on the ground as in electric railways, or overhead. Of the third system, the subject of this Paper, a good deal of experience has been obtained. Telegraphic practice in overhead-line construction, gradually developed during 70 years, is now well established. Tramway overhead work has been rapidly developed in 16 years. Overhead construction for the electrical transmission of power is making a beginning; and while hints may be gathered from other countries, British practice in this, as in all other branches of engineering, is sure to acquire characteristics of its own. It is premature to try to recognize them at present, but, as might be anticipated, solidity and permanence are pronounced features of most of the electrical lines which have been built.

The problem seems to be a simple one, namely, to suspend six, or at the most nine, wires on insulators at a height sufficient to clear ordinary traffic. The peculiarity of the work is that the fall of one of these wires might be a source of danger, since, under certain circumstances, to touch it would result in instant death.

The subject is regarded here primarily from the point of view of security, but having due regard to the fact that exaggerated solidity of scantlings, unreasonable excellence of quality, and fastidious precautions, will simply render overhead electrical transmission impossible. It is assumed that the electrical pressure

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employed is such as to be liable to give a fatal shock, namely, above 600 volts continuous or 250 volts alternating.

The object of this Paper is to elicit discussion rather than to impart information. It hardly touches on electrical matters, but deals mainly with the mechanical considerations of construction.

Wires.

Sizes.—There are no less than seven different ways of describing the size of a wire:—the diameter in Standard Wire Gauge, the diameter in mils or thousandths of an inch, the diameter in millimetres, the sectional area in square inches or in square millimetres, the weight in pounds per mile, and the area in circular mils. (American influence among tramway-engineers sometimes introduces Brown and Sharpe sizes for trolley-wire, making an eighth way.)

The Standard Wire Gauge is sufficiently well recognized, but the steps by which the sizes differ are too large. Engineers concerned with distribution of electric light and power have accustomed themselves during the last few years, when dealing with cables, to think in decimals of a square inch. They order cables of a given section in some round number, and it matters little whether a 0·15-square-inch cable is composed of nineteen strands of wire 0·101 in diameter, or thirty-seven strands of 0·072. The second of these sizes happens to be No. 15 S.W.G., and 101 mils is about half way between No. 13 and No. 12. S.W.G. is therefore falling out of use for many purposes. The Post Office engineers alone describe wires by weight in pounds per mile. Many telegraph-engineers know but little of S.W.G. sizes, and the description of a copper wire as weighing 200 lbs. per mile conveys little or no information to most engineers engaged in electric-light and power work. The circular mil is a strange American notion which needs no attention here.

Materials.—If the price of aluminium did not rise in "sympathy" with that of copper, some consideration would have to be given to that material. The choice between aluminium and copper depends on little else than price. Aluminium can cost 2·13 times as much as copper per pound, and still cost the same as copper for a given length as far as electrical resistance is concerned. The jointing is not easy, and is perhaps not satisfactory. The use of aluminium would entail no alteration in the general design of a line; allowance would have to be made for its small tensile strength (about 11½ tons per square inch), the greater sag, a tension only one-half or one-third that of copper wire, its ductility, its liability to abrasion,

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its temperature-coefficient (which is about 34 per cent. higher than that of copper), and its larger diameter in connection with wind-pressure. This larger diameter puts aluminium out of court where an insulating covering has to be used, but it may perhaps present some advantage when very high electrical pressure is to be employed.[1]

Iron, used largely for telegraph-work, is unsuitable for alternating currents. Ordinary steel has been used for some long spans, and it is possible that some of the new non-magnetizable steels might be employed for overhead lines. Galvanized steel wires are used for stays and for cradles.

Copper, then, is the material for the conductor. Hard-drawn pure copper is amply strong enough. All bronzes offer higher resistance but no compensating advantages. A suspended copper wire may be regarded as an ideal engineering structure. Nothing could be more easy to erect, more homogeneous in quality, more simple in form, or more uniform in lines of stress; and the process of its manufacture imposes a severe test on its tensile strength. The conductors used for tramway-work and called "trolley-wires" are sometimes unworthy of the name of wire. They are little else but rolled rod, drawn perhaps once through a draw-plate to give a wire-like finish. The consolidation produced by the draw-plate benefits each smaller size in succession. The strength is believed to be mainly in the skin. In order to exclude soft and comparatively weak trolley-wire the Electric Tramways Sub-Committee of the Engineering Standards Committee has recommended that wire larger than 00 S.W.G. (0·348 inch or 8·84 millimetre diameter, 0·095 square inch section) should have a minimum tensile breaking-stress of 22 tons per square inch, and wires smaller than and including No. 00 should stand at least 24 tons per square inch. The minimum breaking-stress allowed by the Post Office for hard drawn copper wire is about 30 tons per square inch for the small sizes, and falls off to about 27½ tons for wires of 4½ to 6 S.W.G.

Fig. 1 shows the tensile strength of copper wire, plotted in areas as ordinates, and tons per square inch as abscissæ. It is probably not necessary to propose an absolute minimum of 22 tons per square inch, for large solid wire is not likely to be used in future. The Swiss Federal Council's rules of July, 1899, give 30 kilograms per millimetre, or 19·4 tons per square inch, as the minimum up to

[1] See H. W. Buck, "The Use of Aluminium as an Electrical Conductor." Transactions of the International Electrical Congress, St. Louis, 1904, vol. ii, p. 313.

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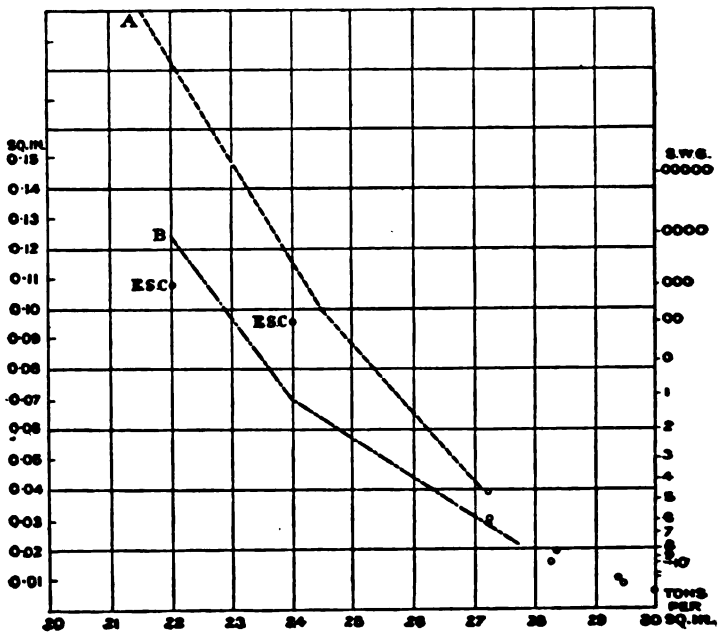
8 millimetres diameter (No. 0 S.W.G.), that is, probably a soft extensible wire.

It seems desirable to use stranded wire for large conductors. It is true that a stranded wire offers more surface and perhaps roughness to the wind, that the interstices may afford lodgment for dirt which may induce corrosion, and that the jointing may be more troublesome than with solid wires; but a great gain results from the higher tensile strength of the smaller constituent wires. The stranded conductor can be made with a hemp core, as is

Fig. 1.



PROPOSED MINIMUM TENSILE STRENGTH OF HARD DRAWN COPPER WIRE.

common in mining-work, and the resulting elasticity is highly beneficial to the stability of the line. The dots in the lower corner of *Fig. 1* are Post Office standards. The dots marked "E.S.C." are the Engineering Standards Committee limits for trolley-wires. The lines A and B represent the proposals of two manufacturers. There is not necessarily any difference in quality in these two proposals. The higher tensile strength is probably secured at the expense of elongation.

Next to tensile strength, the most important quality of the wire

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is its ductility. The Engineering Standards Committee has resolved that for telegraph-material, hard-drawn copper should be defined as that which will not elongate more than 1 per cent. without fracture. But, from the point of view of safety, it is desirable that the wire should not be brittle; and instead of restricting the elongation to not more than 1 per cent. in 8 inches, it seems better to specify that the elongation shall be not less than 1½ per cent. Some limit of elongation may be necessary, but the tensile strength proposed cannot be attained by soft wire. A limit of 3 per cent. in 8 inches has been suggested.

Post Office experience shows that while copper wires are erected with a nominal factor of safety of 4, they have sometimes been coated with frozen snow until the normal stress was increased 32 times, and yet they did not break.[1] This factor of safety may be called nominal because it takes no account of ductility or of elasticity. If a span of wire is exposed to an extraordinary stress, it is better that it should acquire a permanent elongation than that it should break, so long as it does not hang so near the ground as to be within reach. The increase in the sag would be noticed by the patrol, and if necessary it might be taken up.

It has been said that a factor of safety is a factor of ignorance. A factor of safety of 5 seems to be suitable for hard drawn copper wire. If all the conditions of strength and of stress were known, a factor of safety of 1·01 would suffice.

Fig. 2 gives the result of tests made by Mr. F. O. Blackwell[2] on a 60-inch length of wire 0·168 inch in diameter, which had already been broken in the testing-machine at 60,900 lbs. per square inch, and had consequently taken the maximum set. The starting of the curve at 6,000 lbs. per square inch probably means that this stress was needed to straighten out the specimen. It may be argued that the tendency to curl, if it affects the test, should be included as part of the characteristic of the material.

It is as difficult to obtain information about elasticity as about the ductile elongation of hard drawn copper wire. Further information about hard drawn copper wire is greatly needed. Every bell-hanger's boy knows the effect of "killing" copper wire. Anyone who has used a draw-plate knows that copper wire, and, indeed, all other wires that are annealable, go through a wide range of qualities between the dead soft annealed state and the overdrawn brittle wire

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[1] See Mr. J. Gavey's remarks in the discussion, *post*, p. 223.—Sec. Inst. C.E.

[2] "Conductors for Long Spans." Trans. International Electrical Congress, St. Louis, 1904, vol. ii, p. 334.

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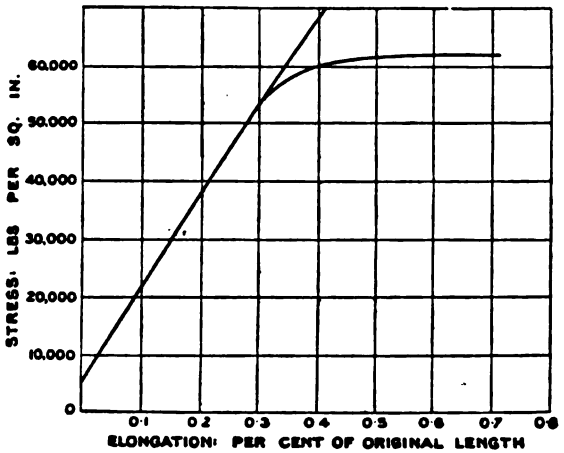
which will not pass through another hole. At one extreme the wire is obviously soft, pliable, apparently weak, and of very low elastic limit. In some proportion to the reduction of area, by being drawn through lubricated holes it becomes harder, stiffer, more springy, stronger, and will "pull out" only a little before breaking. Some of these qualities are important to engineers, some are not.

Considerations of cost will prevent the use of very large and very heavy wires. No. 0000 S.W.G. (0·4 inch in diameter, 0·126 square inch section) is sometimes used for tramway-work, but it is not likely that this will be used for transmission of power over considerable

Fig. 2.



STRESS-STRAIN DIAGRAM FOR HARD DRAWN COPPER WIRE 0·168 INCH IN DIAMETER, 60 INCHES LONG.

(The wire had been previously stressed to 60,900 lbs. per square inch.)

distances; a lower limit is necessary. In Switzerland[1] a wire less than 3 millimetres in diameter (No. 11 S.W.G., 0·01 square inch section) may not be used. The German limit[2] is 10 square millimetres (0·0155 square inch section), corresponding approximately to No. 10 S.W.G. Until further experience has been gained, it seems that work which will not warrant the use of at least No. 7 S.W.G. (0·024 square inch section) had better be carried out by underground cable. Reasons for a lower limit will appear in connection with wind-pressure.

[1] Ordinance of the Federal Council, art. 50.

[2] Regulations issued by the Verband deutscher Elektrotechniker, 1905.

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Stresses on the Wire.

The wire is subjected to three stresses:—the stress due to its weight, the stress due to horizontal pressure of wind, and a dynamic stress due to swinging. The first two may be compounded. If, in the consideration of the third, the period of vibration of the poles were taken into account, the problem would give great opportunity for mathematical exercises.

The older engineering text-books treat at some length of the catenary and its properties, in connection with suspension-bridges. For the present purposes, the simpler treatment of the curve as an approximation to the parabola will suffice. The stress due to the weight of the conductor may be calculated from the well-known approximate formula,

$$T = \frac{l^2 w}{8 d}$$

where T is the tension in pounds, l the length of the span in feet, w the weight of the wire in pounds per lineal foot, and d the sag or dip in feet. Tables of sags and stresses for various sizes of wire at various temperatures have been published by different authorities.[1] Elasticity has been designedly omitted in the preparation of the Post Office tables. "The result of this omission is that new lines erected in summer will at low winter temperature have a larger factor of safety and somewhat greater sags than the tables indicate." It therefore follows that in using such tables for the practical erection of lines, the stress on the wires must be measured and not the sag. It is sometimes found convenient to pull wires up to a measured sag, instead of using a dynamometer. It is quite safe to find the sag by trial, and to use it under uniform conditions of temperature and so long as the line is level.

Wind-Pressure.—Wind-pressure on overhead wire lines is not so severe as on such structures as bridges. Post Office practice is to allow 17 lbs. per square foot at a resultant point 22 feet above the ground. The wreck of an electrical transmission-line would be a much more serious matter than the destruction of a telegraph-line, and from the point of view of public safety, as well as of continuity of supply, a higher limit is desirable. A maximum of 30 lbs. per square foot should suffice. The Swiss rules[2] give 100 kilograms per square

[1] For such tables and much valuable information, see "The Construction of Aerial Lines on Roads and Railways." (*Post Office Telegraphs: Technical Instructions*, xiii.) London, 1906.

[2] Ordinance of the Federal Council, art. 54.

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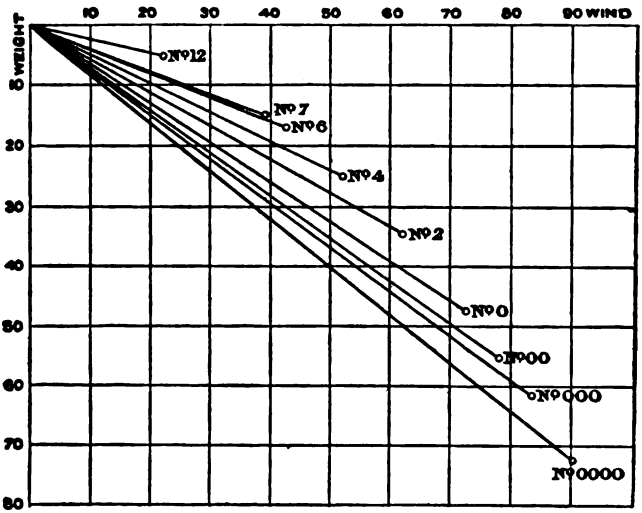
metre, equal to 20·5 lbs. per square foot. The German rules[1] give 125 kilograms per square metre of vertical surface struck, equal to 25·6 lbs. per square foot. The effective surface offered by a cylinder to the pressure of wind is sometimes taken, on theoretical grounds, as the product of two-thirds of the diameter and the length. The Swiss rules allow seven-tenths, and the German rules seem to make no allowance. Taking back-pressure into account, the coefficient for a cylinder appears to be 0·62. High winds do not blow uniformly, and the maximum pressure would not be exerted over the whole span at any one moment. The coefficient

Fig. 3.



WIND-PRESSURE ON WIRE OF VARIOUS GAUGES.

may therefore be taken at 0·6. The experiments of Dr. G. Finzi and Dr. N. Soldati[2] show that the effective resistance is about half that which would be offered by a plane of the same projected area. Mr. F. O. Blackwell and other authorities take one-half as the coefficient.

Since the weight of a wire varies as the square of its diameter and the wind-pressure only as the diameter, the effect will be much greater on small wires than on large. The vertical scale of *Fig. 3* gives the weights, and the horizontal scale the wind-pressures, in pounds, for 150-foot spans of wires of different gauges, taking the

[1] Verband deutscher Elektrotechniker, art. 23 (i), 1905.
[2] *Engineering*, vol. lxxix (1905), p. 461.

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coefficient at 0·6. The slanting lines show the resultants, and are the angles at which the maximum wind-pressure of 30 lbs. per square foot would deflect spans of different gauges. If the wires were being erected and pulled up to their proper sag during a hurricane, the resultant stress ought to be substituted for the mere weight as the basis of the calculation of the sag.

The weight of a span of 150 feet of No. 12 is 4·8 lbs. The wind-pressure on it is 23·5 lbs., the resultant is 23·8 lbs., or about 5 times the weight. Wind-pressure on No. 0000 is one-and-a-quarter times the weight. This greater effect on slender wires makes some limit desirable. It appears that for high-pressure work No. 6 (0·02895 square inch section) or No. 7 (0·0243 square inch section) is the smallest that should be used.

The German rules state definitely that overhead wires for high electrical pressures must be bare, but where corrosive fumes may be expected a protective covering is permissible. This is a sound rule; for, although an insulating covering on a telephone-wire is a useful protection against accidental contact with a trolley-wire, no reliance can be placed on the use of continuous insulation for preventing shocks from high-pressure conductors.

It is customary in tramway practice to avoid joints in the trolley-wire, except at special splicing-ears or section-insulators, and as the conductors for high-pressure transmission-lines are not more costly per mile than trolley-wires, and generally much less costly, it is desirable that no joints should be allowed in the run of a span, but that the ends of the wires should be shackled off at suitable insulators.

Poles.

The wires are carried on steel or wooden poles. It is quite possible that reinforced concrete will be used in some cases. It is not probable that tubular steel poles will be used for this work, although they are used largely for telegraph-work in India and the Colonies. The Engineering Standards Committee has adopted certain dimensions for tramway-poles, and the type is popular among tramway-engineers, but it cannot be considered to be an altogether satisfactory design. The chief advantage of a tubular over a lattice pole is the thoroughness with which it can be painted, and the chief defect is its stiffness. Many designs for lattice poles have been prepared, and, so far as the Author is aware, the line of light poles over Llanberis Pass in North Wales was the first example in this country. The original scheme was to lay a cable along this route, on account of the risk of falling rocks, but difficulties arose about

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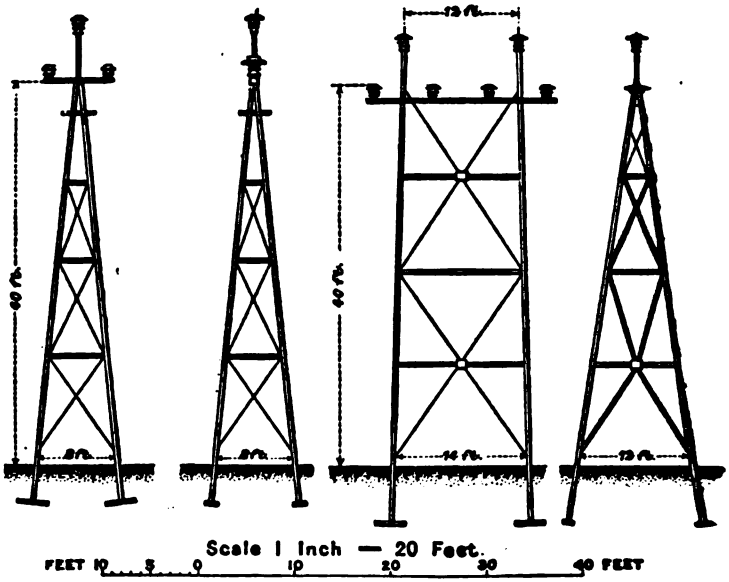
interfering with tourist-traffic by opening the road, and the pole line was therefore built. The rest of the important work of the North Wales Power Company is of wooden poles. Peculiarities of climate affect the choice between steel and wood. In India it is supposed that no kind of wooden pole will withstand the white ant, while in England a well-creosoted pole of Swedish fir will probably outlast three or more steel poles. It would be out of place to discuss details of design of steel poles in this Paper. It seems probable that they will be used only for very heavy routes of conductors or for long spans. The difficulty of arranging for way-leaves has proved to be so great that it has been proposed on this

Figs. 4.



account to use high steel towers planted at the intersection of hedges, and to span the route field by field. There is no engineering difficulty, but with long spans the cost per pole increases rapidly, and a practical economic limit is soon reached, depending on local circumstances. Spans of 400 and 600 feet are not uncommon on the Continent; and the transmission-line of the Guanajuato Power and Electric Company in Mexico[1] has only twelve 40-foot towers per mile. *Figs. 4* show single- and double-circuit steel towers used on this line.

[1] Transactions of the American Institute of Electrical Engineers, vol. xxiii (1904) p. 519.

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There is a tendency to adhere, for the present, to the ordinary tramway-span of 120 feet, say forty-four poles per mile, on account of the irregular routes necessary across cultivated land. Spans of forty to fifty per mile are common in America.[1]

Steel poles should be set in concrete, to preserve the metal, and the concrete should be carried up a few inches above the level of the ground. Planting steel poles on a concrete block and fastening them by holding-down bolts does not seem to be desirable. A tall pole would probably be made in sections and put together on the spot. A foundation-section should be set in concrete, and the upper part bolted to it with bolts in double shear. The concrete in which the pole is set should be dropped on to a cast-iron plate, and attached to the pole by a substantial wire bonded to the plate.

The depth at which steel poles should be set in the ground must depend on the soil. In general the following depths should suffice :—

Over-all Length of Pole.	Depth in Ground.
32 feet to 38 feet	5 feet.
39 „ „ 60 „	6 „
65 „ „ 85 „	7 „

All steel poles should be connected together with an overhead earth-wire. This would be useful as a guard-wire if zigzagged below the conductors, but where any such guard is desirable a more complete one is necessary, and it is perhaps better to put the earth-wire as high as possible, to protect the line from lightning. If the poles are thus well earthed, it does not appear to be necessary to take special precautions about either earthing or insulating stay-wires.

Galvanizing, if so thoroughly done as to withstand the rough handling of transit and erection, should add to the life of a pole, but it adds very considerably to the cost. Thin galvanizing would be of little or no use. "Sherardizing" may prove to be better. Steel poles should be well painted with white-lead paint before delivery and as soon as erected, and should be painted with a suitable paint at least once in every 3 years. Tubular poles might go for a longer period without repainting, but more care must be taken in protecting the ground line than is usual with tramway-poles.

The factor of safety of steel poles should be not less than 6, taking the maximum wind-pressure at 30 lbs. per square foot; the pressure on the lee side lattice should be taken as half the pressure on the windward side.[2]

[1] A. J. Bowie, Jr., "Long Span Pole Lines." *Electrical World*, vol. xlviii (1906), p. 367.

[2] Minutes of Proceedings Inst. C.E., vol. clvi, p. 98.

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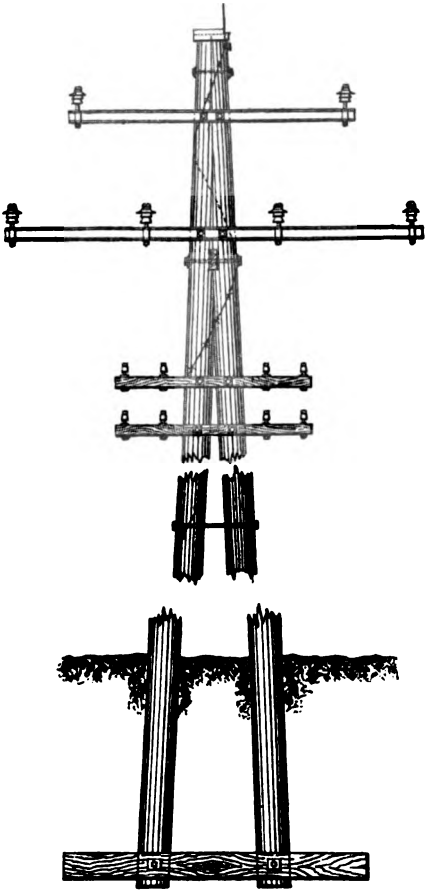
Poles may be stiffened transversely to the route by stays, and in the usual manner at corners, but on the straight run no stays should be allowed to stiffen the poles in the direction of the route. Flexibility in this direction is an advantage.

Fig. 5.



Wooden Poles (*Figs. 5–8*).[1]—While the strength and elasticity of steel poles can be calculated from the tested properties of the material, and homogeneity can be counted upon, the uncertainty of the qualities of wooden poles renders it imperative that a much larger factor of safety should be taken for them. It appears to be recognized English practice to take a factor of safety of 10 for timber structures. A round pole with the natural butt has a considerable advantage over a squared beam, and weakening by boring holes in places likely to be stressed severely is not necessary.

If a pole is strong enough to withstand wind-pressure on itself and on the wires it carries, and is tolerably elastic in the direction of the line, it may be relied upon to withstand the pull of the wires under ordinary conditions, including failure of all the wires on one span in a straight run. The centre of gravity of the projected area of the exposed part of a pole of ordinary taper is within a few inches

[1] The examples here illustrated are :—
Fig. 5.—Standard A pole, County of Durham Electrical Power Distribution Co.
Fig. 6.—Three-wire pole, Clyde Valley Electrical Power Co.
Fig. 7.—Single-circuit A pole, South Wales Electrical Power Distribution Co.
Fig. 8.—Double-circuit H pole, South Wales Electrical Power Distribution Co.

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of the middle of its height. The area exposed to a cross wind by ordinary arms and insulators is small, and as a compromise these may be neglected, and the resultant point for wind-pressure may be taken at half the height, with the coefficient 0·6 for the effective surface.

It is unfortunate that, with such wind-pressure allowances for

Fig. 6.

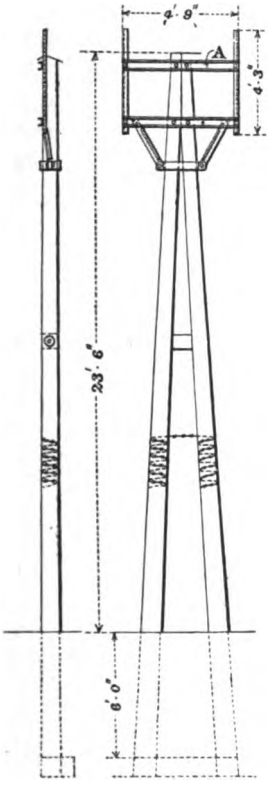
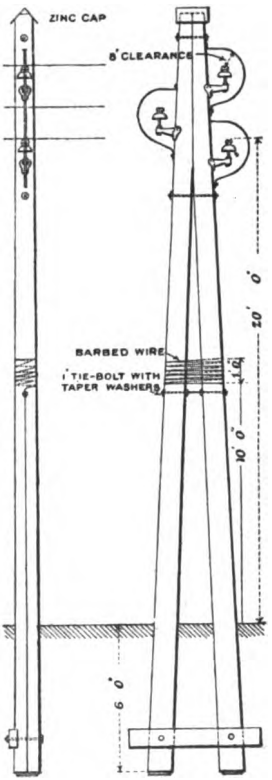
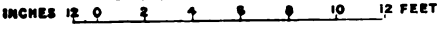


Fig. 7.



Scale 1 Inch — 8 Feet.



wires and poles, and a factor of safety of 10, the diameters are such that for ordinary heights a complete pole is not generally suitable, part of the top having to be wasted. It might be said that Nature knows how to design a tree, and that the foliage may be considered to be equivalent to the wires; but such trees as provide these poles grow in forests and shelter each other. This waste adds very considerably to the cost, but it may be avoided by substituting

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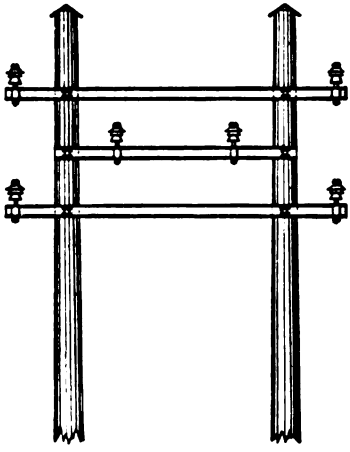
comparatively light A poles built up from two natural poles. For heavy routes of conductors there are advantages in using H poles. Electric-transmission work differs in several respects from telegraph-work. Telegraph-lines are placed as a rule along roads, and very tall poles are often needed to carry the wires over buildings. Transmission-lines go across country, and it is desirable to keep the poles as low as is consistent with a safe clearance for the wires, say 20 feet.

The Author could find no information about the strength and elasticity of wooden poles except in the Paper[1] read before the British Association in 1885 by Mr. (now Sir) W. H. Preece. The questions which specially needed elucidation were the strength of various designs of A poles, the elasticity of ordinary poles, and whether modern processes of creosoting affect the strength. The Author applied for information on these subjects to Messrs. Wade, Sons and Co., of Hull, who are large importers of poles. As soon as they learned that such information was needed, they instructed Professor John Goodman, M. Inst. C.E., of the University of Leeds, to carry out a series of tests, and through their enterprise very useful results[2] have been obtained. Among other points, the most economical design of an A pole was decided.

Fig. 8.



It is evident that the strength of an A pole for side stress varies with the width of the base. But until Professor Goodman tested a number of poles with different splays, it was not easy or perhaps possible to predict the relation between the breaking-load and the splay. The practical result is not the strongest pole, for a 6-foot splay at the base needs so large an excavation and occupies so much space that the cost of wayleaves would be largely increased. The tests at Hull showed that a pair of poles about 36 feet long over all, with a 4-foot splay, or a ratio of height to base of about 8 to 1, gave the best practical results (*Fig. 5*). A scarf joint is made with oak chocks to resist shear. While the increased splay conduces to

[1] "On the Strength of Telegraph Poles." Report of the British Association, 1885, p. 853.

[2] C. Wade. "The Use of Wooden Poles for Overhead Power Transmission." J. Institution of Electrical Engineers, vol. 39 (1907), p. 304.

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strength, the length of the scarf is diminished. With a wide splay only one oak chock can be used and only one bolt can go through the scarf, and the grain is cut at a greater angle, resulting in weakness at the notching.

In other words, the additional strength afforded by a wider base is not worth the additional expense. Such a pole with a carefully designed scarf would be about five times as strong as a single pole of the same diameter. The deflection in the direction of the route is of course about half that of a single pole, and the deflection sideways is about one-seventieth of that of a single pole of the same diameter and length. The ultimate strength of a line built with such poles is probably a matter of foundation rather than of crippling or breaking of the poles. It is better that the foundation should yield than that the pole should break, but it is better still that the pole should bend during extraordinary stress and spring back when repairs have been made. As soon as the attention of the Author was called to flexible steel poles by Mr. C. H. Merz, M. Inst. C.E., he realized the importance of the elasticity of poles in the direction of the route, and recognized the economy of **A** poles; but it remained for Messrs. Wade to demonstrate how great this economy is.

Although the stock sizes of poles do not give much choice, a line may be strengthened at moderate curves and in exposed situations by reducing the spacing of the poles. At angles stays are in general more useful than struts. It is difficult to fit the scarf so that it does not gape when the load comes on the poles, and it is not easy to arrange a good scarf which does not weaken the pole which has to be strutted.

Wooden poles should be chosen in accordance with the Post Office specification, which directs that they should be of sound winter-felled red fir, free from large knots or other defects, and with the natural butt. The poles should be injected with creosote, 10 lbs. per cubic foot.

Unless in rock foundation, the following depths seem suitable for setting wooden poles :—

Over-all Length of Pole.	Depth of Ground.
Under 33 feet	5 feet.
33 feet to 38 feet	6 „
39 „ „ 60 „	7 „
65 „ „ 85 „	8 „

Wooden poles should be set directly in the soil, and the earth should be well punned as it is filled into the hole. In certain places they must be set in concrete. Many poles in the Snowdon district have been set in concrete in boggy ground.

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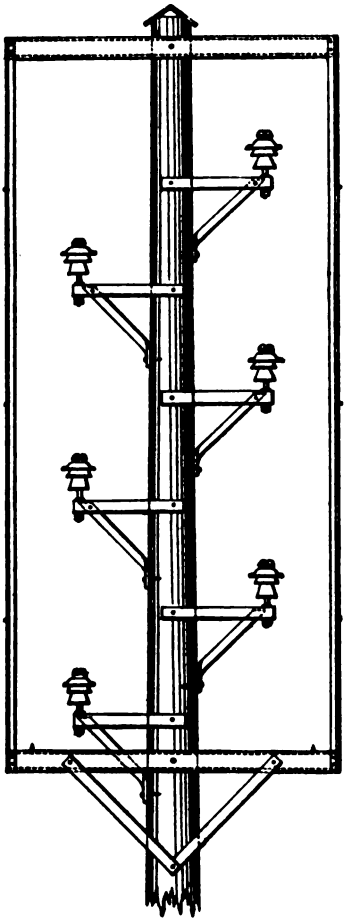
Poles in General.—For the purposes of records and of reports by patrols each pole should be clearly and permanently marked with a number. Danger-notices should be fixed on, say, one pole in five, and on both poles at a road-crossing. A satisfactory form of danger-notice is difficult to find. It should not be too large or too small; the death's head and cross bones does not commend itself to every one; the statement "10,000 volts" can hardly be said to constitute a clear warning of danger. The red zigzag arrow commonly used on the Continent with "Danger!" seems to be in the right direction.

Fig. 9.



Provision to prevent climbing has been made in some cases by fixing spiked collars, but stout barbed wire, coiled at least ten times round the pole for a length of not less than 2 feet, and at a height of not less than 6 or 8 feet from the ground, appears to be better than the spiked collar. This barbed wire is sometimes used as an earth-wire.

When the line crosses a public road, railway, or canal, the angle between the line and the direction of the road, etc., should not be less than 60 degrees. The height of the poles for cross-country work should be sufficient to bring the lowest part of the wires not less than 20 feet from the ground.

Arms.— Arms need not be made of the same material as the poles: wooden arms are sometimes used on steel poles, and steel arms on wooden poles. Channel-steel arms are rather more expensive than oak arms, and malleable iron brackets, well galvanized, are cheaper still, and are suitable for pressures up to 6,000 volts. A wooden arm is liable to be burned through if a live

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wire falls on it. The insulation afforded by a wooden arm is not worth having, and vanishes in wet weather. If wooden arms are used, it is desirable to provide an earthed metal strip on the upper side of each arm. Arms should be slightly notched into the poles; this contributes to the stiffness of A poles. The length depends on the electrical pressure to be used. Wooden arms should have the upper arrises chamfered. Bracing below the arms adds considerably to the strength of a pole, as it distributes the load and lowers the resultant point at which the stress is applied. A 3-inch by 1½-inch British Standard Section channel makes a good arm. The flanges are not wide enough to allow a hole to be drilled, and the insulator pins are clamped to the sides.

Cradles.—For preventing the fall of a conductor where a line crosses a road, no other precaution seems to be better at present than the cradle of wire commonly used on the Continent. These cradles are troublesome to build, are unsightly, and appear to be more likely than any other part of the work to suffer from frozen snow.

It is customary to arrange the insulators of a three-phase line triangularly, and some engineers attach importance to the electrical symmetry of such an arrangement, as a means of avoiding surging of the current. But at a cradle it is desirable that the insulators should be placed one above the other, in order to reduce the width of the cradle, and to allow it to form a deep pocket. It is the width, and not the depth of cradles, which gives trouble in construction. Such an arrangement considerably reduces the cost of a cradle, but in some cases slightly taller poles may be required. Where a few feet of extra height is required, it is sometimes convenient to carry the arms on ironwork above the pole, instead of employing extra long poles.

There are three types of cradles, differing mainly in their terminal arrangements.[1] The first, which is common in Switzerland, consists of a frame of angle-bars forming an ellipse or oblong, attached to a pole (*Fig. 9*). It is pierced with a number of holes, and through

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[1] The examples of cradles here illustrated are :—

Fig. 9.—Double-circuit cradle.

Figs. 10a.—Double-circuit cradle, Clyde Valley Electrical Power Co.

Figs. 10b.—Double-circuit cradle for the Scottish Central Electric Power Co.

Figs. 10c.—Single-circuit cradle, Penrhiwceiber Transmission, South Wales Electrical Power Distribution Co.

Fig. 11.—Double-circuit cradle, Treforest Overhead Lines, South Wales Electrical Power Distribution Co.

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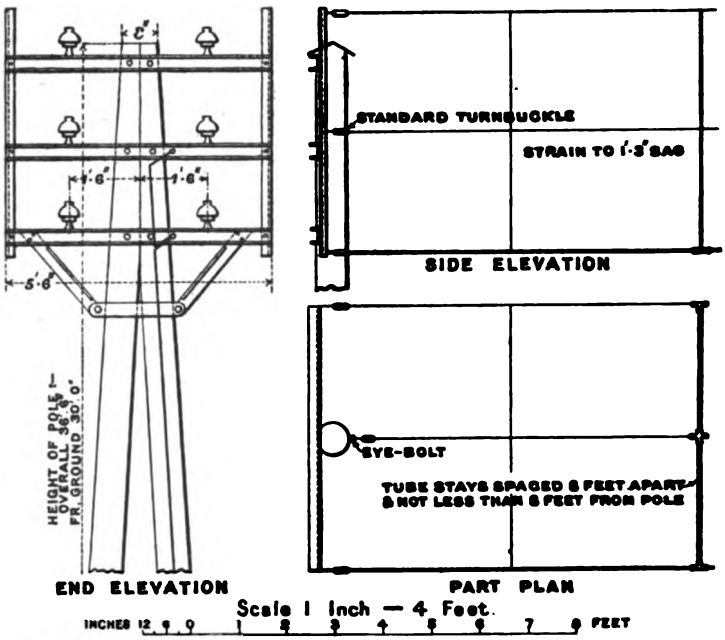
these wires are fastened running parallel with the conductors. Cross wires are bound to the longitudinal wires to form a net. Such cradles were first used in this country by the North Wales Power Company.

A second type utilizes uprights fastened to the ends of the arms (*Figs. 10a*, *10b*, and *10c*). These carry the longitudinal wires. The third type of cradle is slung from special arms (*Fig. 11*). Since wires are more liable to break in a strong wind than in calm weather, it is not unlikely that they will be blown sideways. In

Figs. 10a.


STANDARD TURNBUCKLE
STRAIN TO 1·5 SAG
SIDE ELEVATION
EYE-BOLT
TUBE STAYS SPACED 8 FEET APART & NOT LESS THAN 8 FEET FROM POLE
PART PLAN
HEIGHT OF POLE OVERALL 36'6" FR. GROUND 30'0"
END ELEVATION
Scale 1 Inch — 4 Feet.
INCHES 12 9 0 1 2 3 4 5 6 7 8 FEET

order to catch them, the upper edge of the cradle should be arranged so that a line drawn from that edge to any wire shall make an angle of not less than 45° with the horizontal. There is no difficulty in securing this condition with the first two types of cradles, but with the third it is not so easily arranged, and a good deal of anchoring back to the next pole, or staying to the ground, is needed. Cradles of considerable length, and all wide cradles, need stiffeners or struts to prevent the outer wires from being drawn together by the cross wires. Light steel tubing has been used for this purpose.

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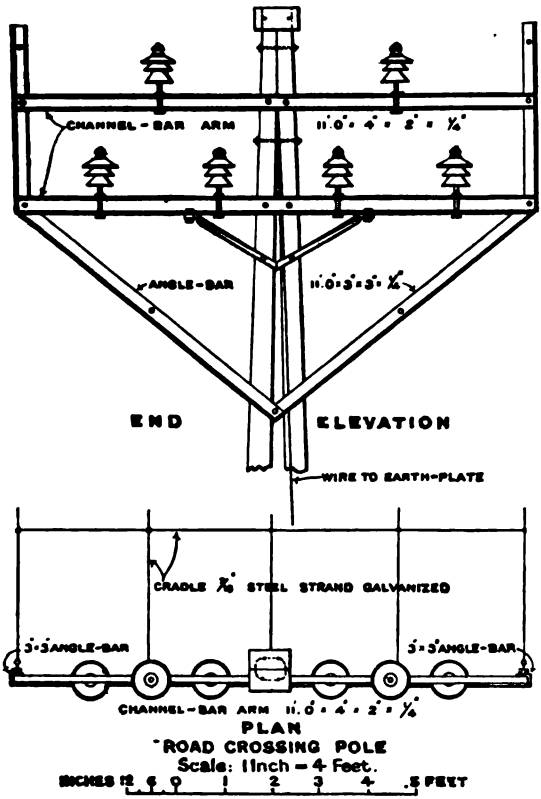
A cradle has two distinct objects, like the guard-wires of a tramway. First, to ensure that a falling wire shall become earthed before it can do any mischief, and secondly, to prevent a broken wire from coming within reach of the ground. To secure the first of these objects the cradle must be thoroughly earthed and must be mechanically and electrically capable of dealing with the blow of a

Figs. 10b.



fallen wire and of the short-circuit current which will pass. In many cases satisfactory earthing can be secured only by connecting all the poles together by a substantial earth-wire, putting all the earth-plates in parallel.

If time-limit circuit-breakers are provided for the purpose of delaying the opening of the line for a second or two in case of a transient accidental short-circuit, they must be arranged to open

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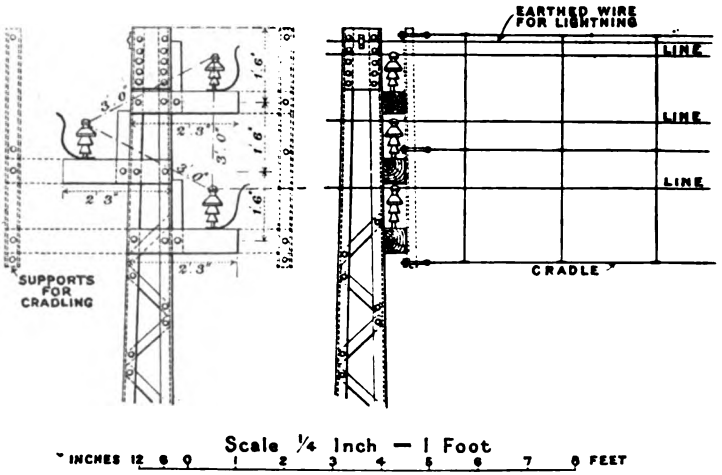
instantly if a wire falls into a cradle. Delay might cause the burning through of successive cross wires. On the other hand, complete safety is secured if a wire falls into a well-insulated cradle of such a construction that an end cannot dangle through. Such a cradle, of large dimensions, is built below the mass of wires which enter Milan from Paderno. The longitudinal wires have six globe insulators in series at each end. This cradle is of the third type, and the stiffeners are neatly curved.

In the case of an earthed cradle, it would be sufficient if a fallen wire struck a cross wire, established a short-circuit, and was cut out of circuit. But in the case of an insulated cradle the fallen wire would remain alive. In the second case it is necessary that the

Figs. 10c.



cross wires should be so close (say 2 feet apart) that the fallen wire cannot wriggle through; and it must be remembered that a hard-drawn wire does not always fall limp in a straight length. A cradle was built with a wire netting of large mesh, which formed in less than 2 days a receptacle for dead cats, old boots, and empty tins.

A reason for reducing the number of wires in the case of an earthed cradle is to diminish the risk of accumulation of snow. Snow is more likely to lodge at the cross bindings than on a straight run of wire. The lowest part of a cradle should be not less than 25 feet from the ground.

The Swiss rules suggest wires of different sizes for different parts of a cradle, but it is probably better to use one gauge throughout,

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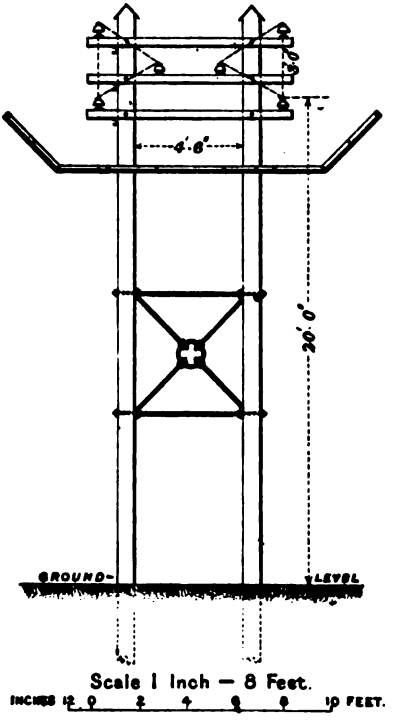
say, 7/16 or 7/14 S.W.G. galvanized steel, according to the length of the cradle and the current transmitted. There will then be no risk of using for longitudinal wires the lighter gauges intended for cross wires. Another reason is that, though the longitudinal wires must afford mechanical strength to support the cradle, the cross wires must be electrically suitable for making a dead short-circuit with a fallen wire. In building a cradle the difference of expansion of copper and of iron should not be forgotten. Copper will sag more than iron in summer.

Fig. 11.



A cradle is usually put together flat on the ground and then lifted into place and attached to its supports. Another way is to sling a few longitudinal wires across and then bind the cross wires on, one or two at a time, the men working on ladders, and the cradle being pulled across yard by yard until complete.

A German rule suggests that "wherever the breaking of a pole or of a conductor might cause danger to a passer-by, the conductors shall be erected at such a height that if broken, the hanging ends shall be not less than 3 metres from the ground, or devices shall be used whereby the falling of the conductor shall be prevented, or other precautions shall be taken by which the hanging ends shall become dead." The first of these regulations does not seem to be very feasible, the second is met by a cradle, and no hint is given about the details of the third.

The principle of the earthed cradle is so attractive that several attempts have been made to substitute for it the equivalent of two cross wires only, and to dispense with all the others and with the longitudinal wires. The arrangement takes the form of an earthed

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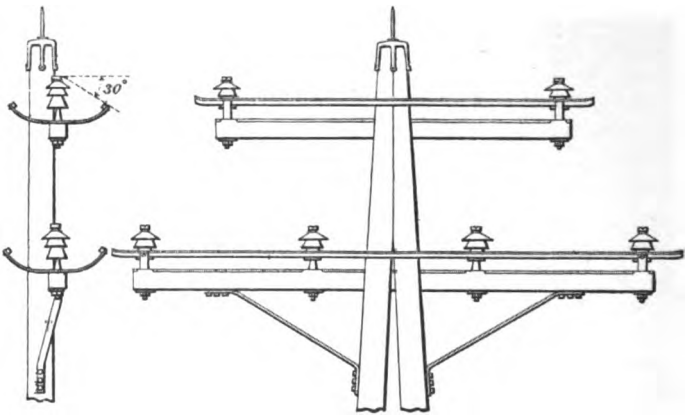
metal bar close below each wire and held at a short distance from the insulator. Such an arrangement is shown in *Figs. 12.*

It is difficult to settle the minimum angle which the wire should make before touching the cross-bar. An angle of 30 degrees is shown in *Figs. 12.* But a stiff wire breaking near an insulator need not drop at all, the increased sag of the slack span behind may tilt the broken end up. This is less likely to occur when there are a number of wires. In order to meet such a case metal rings have sometimes been used encircling the wire, and ready to earth it if it moves much in any direction; but these were not found to be satisfactory on the Valtellina railway.

Crossing of Telegraph-Wires.—When telegraph- or telephone-wires

Figs. 12.



Mr. C. H. Merz's Earthing-Bar.

cross above or below a transmission-line it is necessary to ensure that accidental contact cannot take place. The telegraph-wire is more likely to break than the transmission-wire. Cradling may be provided above or below the transmission-wires. If telegraph-wires cross above, the network of the cradle must be close enough to prevent the possibility of a wire curling in. If they pass below, an ordinary cradle will suffice. It is better that the telegraph-wires should pass below. In Sweden it is the practice to carry the transmission-line over the telegraph-line on two tall poles with so short a span between them that a broken transmisssion-wire will hang down without touching the telegraph-wire. Tall poles and unevenly balanced spans seem to be undesirable.

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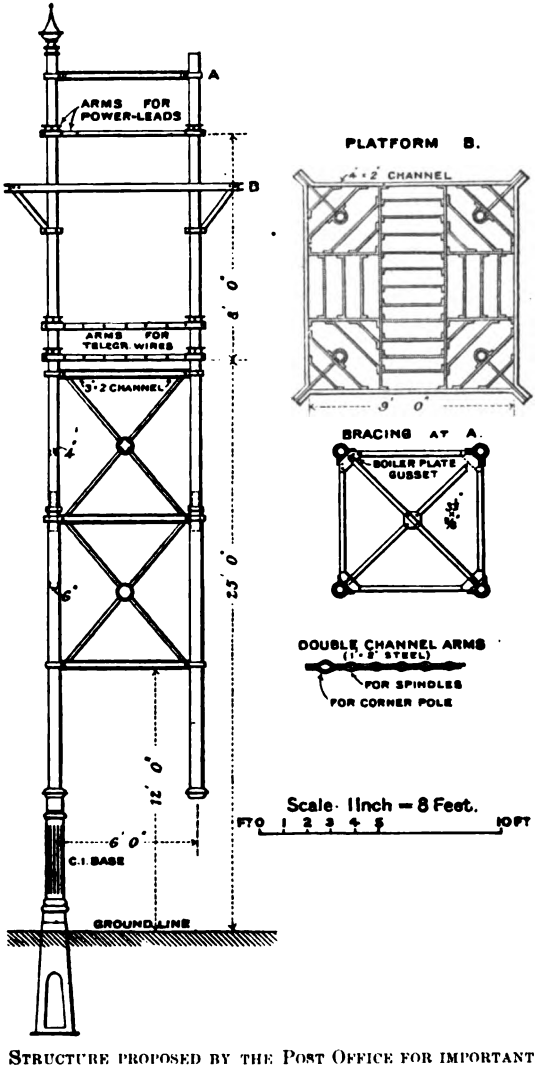
The Author has asked Mr. J. Gavey, M. Inst. C.E., to consider the method of effecting a crossing at a pole, and a plan has been

Figs. 13.



FOUR-POLE STRUCTURE PROPOSED BY THE POST OFFICE FOR IMPORTANT CROSSINGS.

prepared by the Post Office (*Figs. 13*). An H pole, or, in the case of important lines, a set of four poles would be used. The trans-

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mission-lines are carried above and the telegraph-lines below. The crossing is as nearly as possible at right angles. Post Office linesmen have access only to the telegraph-wires.

Among the conditions for crossing telegraph-wires by high-pressure circuits the following have been arrived at by the Post Office:—

"That where power lines cross high roads carrying the Postmaster-General's telegraphs, a joint structure be erected for the support of the power line and the telegraph line respectively. This structure to consist of two or four poles, either of wood or iron, as the case may be, suitably braced together to ensure: (*a*) that in no circumstances can it be torn down by the failure of either the power line or the telegraph line under storm stresses; (*b*) that the power line shall be erected on the upper portion of the structure, and shall be screened from the telegraph wires below by an iron grid or lattice platform, which will absolutely prevent the possibility of contact between the two series of wires; (*c*) that this lattice platform shall be put to earth so as to short-circuit any power lines that may come in contact with it; (*d*) that this iron platform shall be effectively earthed by an insulated wire of sufficient gauge, which shall be protected from interference by enclosure in a wrought-iron pipe."

Insulators.

The electrical considerations relating to insulators are for the most part beyond the scope of this Paper. Up to 10,000 volts a simple petticoated insulator set on an iron pin seems to suffice. English porcelain, well-vitrified, cannot be beaten. It is usual and very desirable to test each insulator under very high electrical pressure before delivery. There is some difficulty in testing a long line to double the working-pressure, on account of the considerable capacity-current, which necessitates a rather large testing-transformer. If, however, a line is not tested to twice the working-pressure, practically no margin is allowed for surging currents which may be present in ordinary switching-operations.

Larger sizes of conductors should be carried in a notch on the top of an insulator on the straight run, but must be bound to the side at angles. At considerable angles, special arrangements must be made. It has been suggested that the wire should lie free in the groove so that if a powerful gust of wind exerts an unusual stress on one span that span will yield and will tighten up the neighbouring spans. But this will necessarily lead to chafing and eventual breaking of the

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wire. An equally useful yielding can be obtained by the use of flexible poles. A free wire, if broken anywhere, would run back over many spans and a considerable length would reach the ground. The best practice seems to be to bind the conductor to the insulator to prevent any motion and consequent wear in the groove. Such binding is well understood in telegraph-work, but it is a much more difficult matter with the large stiff wires used for power-transmission. It may be necessary to use clamps for holding the conductor to the insulator. Several patterns have been designed. In American practice it is said that if a conductor breaks it always slips over the insulators for a considerable distance on both sides of the break and distributes the strain.[1]

It is important that, if an insulator fails either by splitting or snapping of the pin, or from stone-throwing, the wire should fall no lower than the arm. In some cases hooks are provided standing up the ends of the arms, as in Post Office practice, but proportionally stronger or iron straps are looped over the insulator as in *Fig. 7*.

If a wire falls away from an arm it will hang with a double sag on a double span. It is important that it should still be out of reach, and this would be the case under ordinary circumstances. But it might happen that it would touch a stay-wire. Where this is possible, strain- or shackle-insulators should be inserted in the stay, dividing it into two parts, the lower part being well out of reach of the fallen wire.

It is common practice to run telephone-wires on the same poles as high-pressure transmission-wires. Special telephone-instruments are then necessary. The vertical space between the transmission-wires and the telephone-wires should be at least twice the sag of the former.

Lightning-protection is a very important subject, particularly in connection with mixed circuits of overhead work and underground cables, but it does not come within the scope of this Paper. It is probable that since there are different kinds of lightning-discharges several different kinds of lightning-arresters or dischargers should be used in parallel at important points. The well-known horn discharger is an excellent arrangement for extinguishing an arc, but for use as a lightning-arrester the spark-gap needs adjustment for different kinds of weather if used out of doors.

When the triangular arrangement of wires is adopted the risk of contact by the swinging of wires together may be avoided by

[1] Blackwell on "Conductors for Long Spans." *Loc. cit.*

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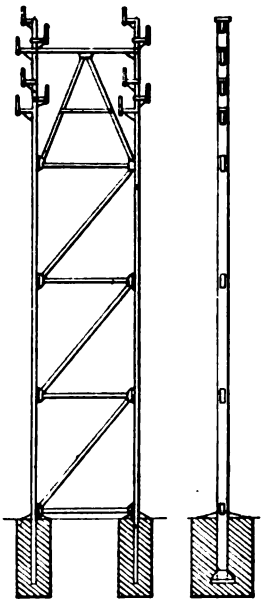
arranging them thus ∵ instead of ∴. Considerably less distance can be permitted between wires when this arrangement is adopted, and it is specially desirable for long spans.

Flexible Poles.

Terminals and poles where the route makes a change of direction of more than 10 degrees or 15 degrees must be able to resist unbalanced stresses. Stays are generally used in such cases to stiffen the poles. But on a straight and level run with uniform spans the pull on a pole due to conductors is practically balanced. The pull each way may be 2 or 3 tons, but so long as this is maintained no demand is made on the strength of the pole by this pull. If all the wires break on one side, the pull is unbalanced, and if the pole is very stiff and tries to resist this pull, it must be very strong. But it is a mistake to use a stiff pole under such circumstances. If the pole bends, the act of bending will shorten the span next to the break, and this will relieve the stress. So important is this relief, that steel lattice poles have been designed, by Mr. Guido Semenza and others, to be flexible in the direction of the route (*Figs. 14*).[1]

Figs. 14.



Flexible Poles, used on a 15,000-volt Line at Trezzo, N. Italy.

Wooden **A** or **H** poles naturally offer such flexibility as they possess in the right direction. The pole next to the break is the most strained, and the span next to the break is the most reduced in length. The deflections of the successive poles diminish, until after five or six spans the effect is negligible. The number of spans affected depends on the initial stress on the wires. In tramway-work the same effect is to be noticed when a trolley-wire breaks.

The problem has been considered mathematically by several writers, but not always in a satisfactory manner. Mr. A. J. Bowie, Jr.,

[1] G. Semenza, "European Practice in the Construction and Operation of High-Pressure Transmission Lines and Insulators," Trans. American Institute of Electrical Engineers, vol. xxiii (1904), p. 147.

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the author of several mathematical articles on overhead wires, gives[1] more than one mode of determining the stresses. At the Author's suggestion Mr. W. H. Logeman, M.A., of Trinity College, Cambridge, has investigated the matter, adopting Mr. Bowie's method and applying it to a partly graphical working; and Mr. Logeman's treatment of the problem is given in Appendix I. Taking the well-known approximate formulas,

$$L = l + \frac{8\,d^2}{3\,l}$$

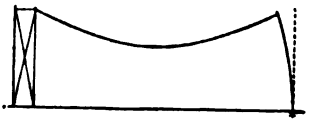
$$T = \frac{l^2\,w}{8\,d}.$$

where L is the actual length of the wire in feet, l the span in feet from insulator to insulator, d the sag in feet, T the tension in pounds, and w the weight of the wire per foot, the following equation, connecting stress with length of span, may be found—

$$L - l = \frac{l^3\,w^2}{24\,T^2}.$$

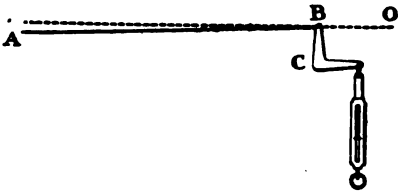
First, consider one span (*Fig. 15*) with a rigid anchor-pole and a break in all the wires beyond the first pole. It is evident that equilibrium is established when the stress deflecting the pole is equal to the stress corresponding with the reduced span. Let the deflection of the pole be proportional to the horizontal stress. The condition of the equilibrium may be found by a rather troublesome cubic equation, but a graphical solution for this simple case is easy.

Fig. 15.



Let A B (*Fig. 16*) be part of a span of wire attached to a bent lever C, and let the stress be measured on the spring-balance D. If the fulcrum of the lever is carried to the left, slacking out the span, the stress is diminished. If it is carried to the right the stress increases, and would be indefinitely great if B could be brought up to O. A pencil carried by the spring-balance would draw the curve ADE (*Fig. 17*).

Fig. 16.



[1] "Strains in Pole Lines," *Electrical World* (New York), vol. xlviii (1906), p. 953.

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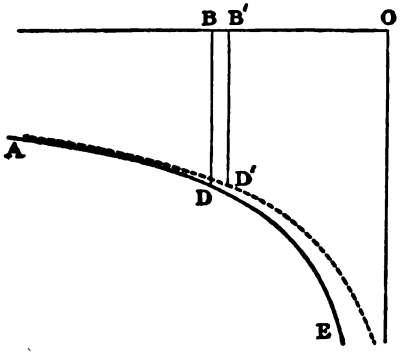
This curve is the graph of the equation

$$L - l = \frac{l^3 w^2}{24 T^2}.$$

To calculate it, in any case in which l, T and w are known: find $L - l$, invert the slide of a slide-rule and set $L - l$ on the inverted A scale, over T on the D scale; then read off $L - l$ for any value of T.

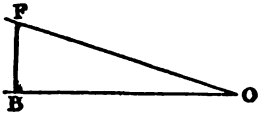
Fig. 17.



The point O (*Fig. 17*) is the limit to which an inextensible wire would be stretched by an indefinitely great stress. If the end of the wire be slacked out to B, B D represents the stress. Let the wire be elastic, and let a stress B D stretch it an amount B B′, draw B′D parallel to B D, then D′ is a point on a curve which takes account of the elastic extension of the wire.

Let O (*Fig. 18*) represent the normal position of an insulator on a flexible pole. Let the stress B F deflect the pole from O to B. The stress is in the direction of the deflection, but for this graphical treatment it is drawn at right angles, as in *Fig. 17*. Combining *Figs. 17* and *18* in one diagram *Fig. 19* is obtained.

Fig. 18.



Young's modulus is taken at 13,000,000 lbs. per square inch. Let there be six wires, each No. 000 S.W.G., weighing 0·42 lb. per foot each, pulled up with a stress of 1,000 lbs. each on a span of 300 feet. Let the pole bend 3 inches for a stress of 800 lbs. Then $L - l =$ 0·198 foot, where L is the length of the wire laid out straight on the ground without tension. From this quantity and 6,000 lbs. the dotted curve (*Fig. 19*) may be calculated. Let O O′ be 0·198 foot. The stress 1,000 lbs. stretches each wire 0·212 foot. Make O O″ equal to 0·212 foot and join O″ E. For various extensions, such as R S, plot T U = R S, and thus find the full curve D E. Let O E be the normal stress of 6,000 lbs. Draw O F to represent the deflection of the pole, *i.e.* 0·25 foot for 800 lbs., and draw G O, making the

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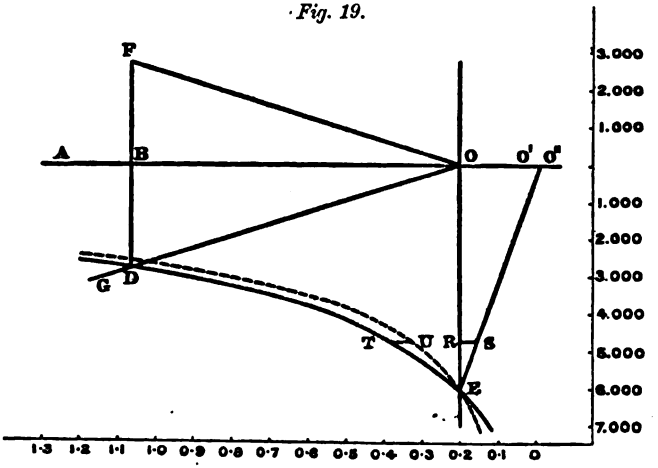
angle G O A equal to the angle A O F, cutting the curve at D. Draw D F cutting O A at B. Then B D, the stress on the wire, is equal to B F, the stress deflecting the pole. B O is the deflection of the pole. The stress is found to be 2,770 lbs., or only 46 per cent. of the original stress of 6,000 lbs., and this with a rather stiff pole.

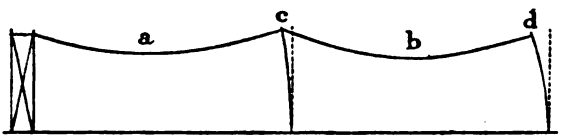
Fig. 19.



Mr. Logeman's result is 2,750 lbs. The deflection measured from O is 0·865 foot. For an inextensible wire it would be 0·825 foot.

If instead of one span there are a number of spans, the stress on the pole next to the break will be greater, and the other poles will be deflected and the stresses on the other spans will be relaxed. But the effect is not appreciable beyond the fourth or fifth pole,

Fig. 20.



and the stress on the pole next to the break will not be increased by more than 20 per cent.

The graphical treatment may be extended as follows. The stress on *a* (*Fig. 20*) is evidently equal to the stress on the span *b* plus the stress deflecting the pole *c*. *Fig. 21* is a development of *Fig. 19*.

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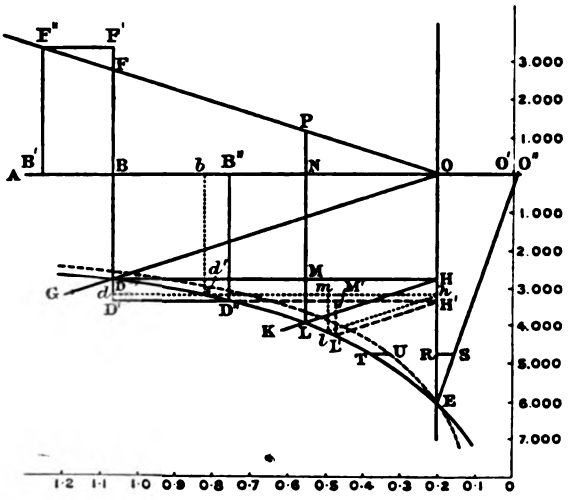
Draw D H (*Fig. 21*) parallel to A O, and K H parallel to G O, cutting the curve at L. Draw L M N P, cutting D H at M, B O at N, and F O at P. Then, as a first approximation, N P is the stress deflecting pole *c* through the distance O N, and N L is the stress on span *a*, and is equal to B D, the stress on span *b*, plus the stress N P or M L.

But this is not a condition of equilibrium, for the deflection of pole *c* lengthens span *b* and further deflects pole *d*. Assume that half of this stress lengthens span *b* and that the other half deflects pole *d*.

Let F F′ and D D′ each equal half P N the additional stress. Then B F′ is the first approximation to the stress deflecting pole *d*.

Fig. 21.



Draw F′ F″ and F″ F′, then O B′ is the first approximation to the deflection of pole *d*. Draw D′ D″ and D″ B″. Then B B″ is the first approximation to the lengthening of the span *b* due to the movement O N of pole *c*.

But the construction B D H L P no longer holds good. Make the construction shown by the broken lines D″ H′ L′ M′. Take D *d* equal to half M′ L′. Then B *d* is the second approximation to the stress. Draw *d d′ b*, then *B b* is the second approximation to the lengthening of span *b*. Continue the construction by the dotted line *d h l m*. The third approximation to the additional stress on the pole next to the break is B D plus half of *m l*. Further approxima-

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tions give values oscillating between D′ and *d*. The final result is about 3,250 lbs. Mr. Logeman's value is 3,075 lbs.

Similarly, the stress due to a third span can be found, and the consequent additions may be made to the second and first spans.

Conclusion.

Board-of-Trade regulations about engineering details should be the embodiment of the best practice of the day. No established practice of overhead-line construction can be said to exist at present. There are only three or four lines of importance; the matter is still in a tentative stage; and the time does not seem to have come for regulations.

One of the conditions for the consent of the Board of Trade to the use of overhead wires is the submission of a description of the system.

The Author proposes to recommend the Board of Trade to adopt a model description of overhead-line work. Engineers can send in descriptions following the model as closely as circumstances permit. It is intended to show the amount of detail required, and not to suggest actual details. This model is given in Appendix II, and, with the permission of the Board of Trade, is submitted for discussion.

The Author wishes to make it clear that nothing in this Paper is to be understood as representing the official views of the Board of Trade.

In conclusion, the Author wishes to express his indebtedness to Messrs. R. W. Blackwell & Co., Messrs. Callender & Co., Mr. C. H. Merz, the Clyde Valley Electrical Power Co., the Scottish Central Electric Power Co., and the South Wales Electric Power Distribution Co., for drawings kindly placed at his disposal.

The Paper is accompanied by nine drawings, twelve tracings and four sunprints, from which the Figures in the text have been prepared.

[Appendixes.

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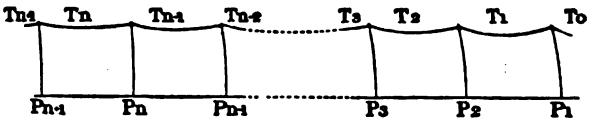
APPENDIXES.

APPENDIX I.

By W. H. Logeman, M.A.

Let l = length of span in feet before break occurs;
L_o = unstretched length of wire in each span (constant);
L = stretched length of wire in span;
E = coefficient of elasticity of wire, given by $L = L_o\left(1+\frac{T}{E}\right)$;
w = weight per foot of wire in lbs.;
T = tension in each span before break occurs, in pounds;
T_n = tension in nth span after break occurs, in pounds;
D_n = deflection of pole P_n;
K = coefficient of elasticity of pole given by D = K × difference of tensions.

Fig. 22.



Consider the formula[1] $$24\,T^2 = \frac{l^3 w^2}{L - l}.$$

Here $$L = L_o\left(1 + \frac{T}{E}\right) = L_o + \frac{T\,l}{E} \quad (\text{since } l \doteqdot L_o).$$

Hence the equation becomes

$$24\,T^2 = \frac{l^3 w^2}{L_o - l + \frac{T\,l}{E}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Now, when the poles bend, the value of $L_o - l$ is increased by the difference of the deflections of the two poles, *i.e.*, by $K(T_n - T_{n-1}) - K(T_{n+1} - T_n)$, or $K(2\,T_n - T_{n-1} - T_{n+1})$.

Hence, if a is the original value of $L_o - l$ in any span before the break occurs, then for the nth span after the break occurs

$$(L_o - l)n = a + K(2\,T_n - T_{n-1} - T_{n+1}).$$

(N.B.—Since the change in l is very small compared to l, the fact that $l^3 w^2$, the numerator of the fraction, is varying may be neglected, though the change in $L_o - l$ cannot be ignored.)

[1] See p. 209.

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Equation (1) becomes

$$24\,T_n^2 = \frac{l^3 w^2}{a + K(2T_n - T_{n-1} - T_{n+1}) + \frac{T_n l}{E}}$$

that is,
$$a\,T_n^2 + 2K\,T_n^3 - K\,T_n^2(T_{n-1} + T_{n+1}) + \frac{l}{E}T_n^3 = \frac{l^3 w^2}{24}$$

or
$$\frac{l + 2KE}{E}T_n^3 + a\,T_n^2 - \frac{l^3 w^2}{24} = K\,T_n^2(T_{n-1} + T_{n+1})$$

or
$$T_{n-1} + T_{n+1} = \frac{l + 2KE}{KE}T_n + \frac{a}{K} - \frac{l^3 w^2}{24\,K\,T_n^2} \quad . \quad . \quad . \quad . \quad (2)$$

Hence, the general equation is

$$\left.\begin{aligned} &T_{n-1} + T_{n+1} = a + b\,T_n - \frac{c}{T^2{}_n} = f(T_n) \text{ say} \\ \text{or} \quad &T_{n+1} = f(T_n) - T_{n+1} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (3)$$

where
$$\left.\begin{aligned} a &= \frac{a}{K} = \frac{1}{K}\left(\frac{l^3 w^2}{24\,T^2} - \frac{T\,l}{E}\right) \\ b &= \frac{l + 2KE}{KE} \\ c &= \frac{l^3 w^2}{24\,K} \end{aligned}\right\} \text{constants.}$$

Now consider any span, say that to the left of P_{n+1}. The tension T_{n+1} in this span is greater than T_n, but less than T, the tension which was in the span before the break occurred. Hence, if in the equations it is assumed that $T_{n+1} = T_n$, too low a value for T_1 will be obtained, while if T_{n+1} be put $= T$, the value obtained for T_1 will be too high. The true value of T_1 will therefore lie between these two calculated values. The higher the value of the number n the more nearly will the two values of T_1 approach each other and the true one.

Take now the figures

$$\begin{aligned} &l = 300, \\ &w = (\text{for six wires})\ 2{\cdot}52 \therefore w^2 = 6{\cdot}35, \\ &T = 6{,}000, \\ &K = \frac{1}{3{,}200}. \end{aligned}$$

Suppose $E = 8{\cdot}5 \times 10^6$, being the product of Young's modulus 13,000,000 into the total cross section of the wires.

Hence

$$\begin{aligned} a &= -42{\cdot}5, \\ b &= 2{\cdot}115, \\ c &= 228{\cdot}5 \times 10^6. \end{aligned}$$

The next thing to do is to plot the curve $y = f(x)$;

that is,
$$y = a + b\,x - \frac{c}{x^2},$$

or
$$y = -42{\cdot}5 + 2{\cdot}115\,x - \frac{228{\cdot}5 \times 10^6}{x^2}.$$

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TABLE FOR DRAWING THE CURVE $y = f(x)$. (*Fig 23.*)

x	y	x	y	x	y
2,600	2,076	3,800	6,413	5,000	9,618
2,800	2,964	4,000	6,989	5,200	10,110
3,000	3,762	4,200	7,545	5,400	10,594
3,200	4,495	4,400	8,083	5,600	11,072
3,400	5,170	4,600	8,606	5,800	11,544
3,600	5,807	4,800	9,117	6,000	12,012

Now since the wires to the right of P_1 are broken, $T_0 = 0$.

$\therefore$ from equation (3)

$$\left.\begin{aligned} T_2 &= f(T_1) \\ T_3 &= f(T_2) - T_1 \\ T_4 &= f(T_3) - T_2 \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (4)$$

and so on.

As a first approximation to T_1, take the mean of the values obtained by assuming, first, that $T_2 = T_1$, and then that $T_2 = T = 6{,}000$. If $T_2 = T_1$, first equation gives $T_1 = f(T_1)$ $\therefore$ T_1 is given by abscissa of point of intersection of curve $y = f(x)$ and straight line $y = x$, *i.e.* (see *Fig. 23*),

$$T_1 = 2{,}750.$$

If $T_2 = 6{,}000$, $\quad 6{,}000 = f(T_1)$, then from curve

$$T_1 = 3{,}660.$$

Taking the mean of these, it is found as a first approximation, that

$$T_1 = 3{,}205 \text{ lbs.}$$

To obtain a second approximation to T_1, first assume $T_3 = T_2$ and then $T_3 = T$, and take the mean of the two values of T_1 obtained.

If $T_3 = T_2$,

$$\begin{aligned} T_2 &= f(T_1) \\ T_1 &= f(T_2) - T_2. \end{aligned}$$

$\therefore$ T_1 is the abscissa of the point of intersection of curve $y = f(x)$, and curve $x = f(y) - y$.

N.B.—Only a small part of the latter curve in the region of $x = 3{,}200$ need be drawn.

$$\begin{aligned} \text{If } y = 4{,}000, &\quad f(y) - y = 2{,}989 \\ y = 4{,}400, &\quad f(y) - y = 3{,}683. \end{aligned}$$

These figures are found from the table given above, and this small portion of the curve is assumed to be a straight line.

Hence $$T_1 = 3{,}075.$$

Similarly, if $T_3 = T = 6{,}000$, T_1 is the abscissa of the point of intersection of curves $y = f(x)$ and $x = f(y) - 6{,}000$.

$$\begin{aligned} \text{If } y = 4{,}800, &\quad f(y) - 6{,}000 = 3{,}117 \\ y = 5{,}200, &\quad f(y) - 6{,}000 = 4{,}110. \end{aligned}$$

Hence $$T_1 = 3{,}310.$$

The mean of these gives $T_1 = 3{,}193$ lbs. as a second approximation.

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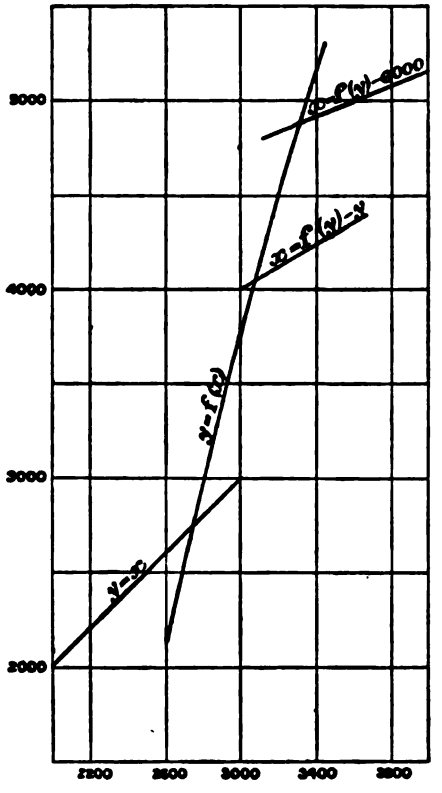
It will be seen that these two approximations differ by an amount hardly greater than the probable error in this graphical method of calculation, and it may safely be assumed that $T_1 = 3{,}200$ is within 1 or 2 per cent. of the correct value.

Fig. 23.



If there had been a great difference between the first and second approximations, it would have been desirable to go one step farther, *i.e.*, first assume $T_4 = T_3$, and then $T_4 = T$, and calculate T_1 in each case.

If $T_4 = T_3$ the equations are—

$$T_2 = f(T_1)$$
$$T_3 = f(T_2) - T_1$$
$$T_3 = f(T_3) - T_3.$$

The simplest way to solve these equations is as follows. First assume a value of T slightly higher than the expected answer, substitute in the first equation and find T_2. Then substitute in the second equation and find T_3 and calculate $\frac{f(T_3) - T_3}{T_3}$. Then repeat the above process with too low a value of T_1, and lastly find by interpolation what value of T_1 will make $\frac{f(T_3) - T_3}{T_3} = 1$.

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Thus, if $T_1 = 3{,}200$, $T_2 = f(T_1) = 4{,}495$ (using curve),

then $T_2 = 8{,}330 - 3{,}200 = 5{,}130$ (by second equation, using curve),

then $$\frac{f(T_2) - T_2}{T_2} = \frac{9{,}930 - 4{,}495}{5{,}130} = \frac{5{,}435}{5{,}130} = 1{\cdot}06.$$

If $T_1 = 3{,}100$ a similar calculation gives

$$\frac{f(T_2) - T_2}{T_2} = 0{\cdot}86.$$

$\therefore$ Solution is $T_1 = 3{,}200 - \frac{6}{20} \times 100 = 3{,}170$.

Next assume $T_4 = T$; then the first two equations are the same as before, but the third is $T = 6{,}000 = f(T_2) - T_2$.

$\therefore$ Using the same figures as before,

$$\text{if } T_1 = 3{,}200 \quad \frac{f(T_2) - T_2}{6{,}000} = 0{\cdot}906$$

$$\text{if } T_1 = 3{,}100 \quad \frac{f(T_2) - T_2}{6{,}000} = 0{\cdot}615.$$

$\therefore$ extrapolating $T_1 = 3{,}200 + \frac{94}{291} \times 100 = 3{,}230$.

The mean of these two results is **$T_1 = 3{,}200$ lbs.**

It is worthy of note that the solutions found on the assumptions $T_2 = T_1$, $T_3 = T_2$, $T_4 = T_3$ are the correct solutions in the cases where P_2, P_3, P_4 respectively are anchor-poles.

i.e., if P_2 is an anchor-pole $T_1 = 2{,}750$ lbs.
„ P_3 „ „ „ $T_1 = 3{,}075$ „
„ P_4 „ „ „ $T_1 = 3{,}170$ „
if there is no anchor-pole $T_1 = 3{,}200$ „

APPENDIX II.

BOARD OF TRADE DRAFT MODEL DESCRIPTION OF OVERHEAD-LINE CONSTRUCTION FOR ELECTRIC PRESSURE EXCEEDING 650 VOLTS CONTINUOUS AND 250 VOLTS ALTERNATING.

NOTE.—This model is intended to show the amount of detail required, and not to suggest actual details. A description should be drawn up following the model as closely as circumstances permit.

1. The supply will be delivered (*a*) direct from the generators through the switchboard to the lines at a minimum pressure of . . . volts; or (*b*) it will be transformed from . . . volts to a minimum of . . . volts by transformers interposed between the switchboard and the lines.

Conductors.

2. (*a*) Stranded cable will be used, consisting of . . . strands of hard-drawn copper wire laid on a hemp core. The sectional area of the copper will be . . . square inch. (*b*) Solid hard-drawn copper wire will be used, having a sectional area of . . . square inch.

3. The conductor will have a breaking load, tested under Post Office conditions, of not less than . . . tons per square inch, and on breaking, the elongation will not be less than . . . per cent. and not more than . . . per cent.

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The modulus of elasticity of the strands, in the case of stranded cable, in pounds for 1 square inch will be . . . and the modulus of elasticity of the cable will be . . . The modulus of elasticity of the solid conductor will be . . .

4. The spans will be in most cases . . . feet, and will not exceed . . . feet.

5. The minimum sag of the conductor will be regulated to give a stress due to its weight (but excluding its elasticity) of not more than one-fifth of the breaking load, at a temperature of 22° F. Wind-pressure will be taken at 30 lbs. per square foot. The effective area of the wire will be taken as 0·6 of the diameter multiplied into the length.

6. The minimum height of any part of the wire from the ground will be 20 feet.

7. No extra-high-pressure conductor will cross any building or will be accessible to any person from any building or tree without the use of a ladder or other special appliance.

Poles.

8. The wires will be carried (*a*) on wooden poles, or (*b*) on poles or structures of iron or steel, hereafter called steel poles.

9. Each pole will be clearly and permanently marked with a number.

10. Danger notices will be fixed on at least one pole in . . . and on each pole at the crossing of a road.

11. Provision will be made to prevent climbing by spiked collars or by barbed wire coiled at least ten times round the pole for a distance not less than 2 feet, but at least 8 feet from the ground.

12. Where guys or stays are used they will be securely anchored. Guys or stays will be used only to stiffen the poles transversely to the direction of the line, except in the case of unequal spans, or in the case of a corner, intermediate anchor or terminal poles.

13. Where a continuous earth wire is not carried from pole to pole each stay will be well connected with earth.

14. Where it is possible, in the event of the breaking of an insulator, for a wire to fall with a double sag and touch a stay, strain or shackle insulators will be used to insulate the lower part of the stay from the part which might be touched by the wire.

Wooden Poles.

15. The poles, if of wood, will be sound winter-felled red fir, free from large knots or other defects, with the natural butt. The poles will be well injected with creosote.

16. Single poles or A poles will be used for the ordinary run of the line. Stouter poles, H poles, or built up or strutted poles, provided if necessary with stays, will be used for terminals, for intermediate anchor poles, for important differences of span, and for corner poles where there is considerable change of direction. Ordinary poles provided with stays will be used where the direction makes a small change.

	Diameter at Top.	Diameter 5 Feet from the Butt.
Single poles	..	..
A poles	..	..
H poles	..	..

17. Poles of ordinary lengths, unless in rock foundation, will be set in the ground to a depth of 6 feet. The earth will be well punned into the holes. Where necessary they will be set in concrete.

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18. The factor of safety for wooden poles will be calculated at 10, for a wind-pressure of 30 lbs. per square foot; the effective area of a round pole being taken at 0·6 of the mean diameter of the exposed part into the length of that part.

Steel Poles.

19. Steel poles will be (*a*) of tubular, or (*b*) of lattice type. Steel poles of tubular type will be painted with oil paint not less than once every . . . years, and poles of the lattice type not less than once in every . . . years.

20. Steel poles will be set in concrete for the purpose (*a*) of preserving the metal, and (*b*) for giving a solid foundation.

21. The concrete below the steel pole will be dropped on to a cast-iron earth-plate not less than 1 foot 6 inches by 1 foot 6 inches by ¾ inch bonded to the pole by a substantial wire or rod.

22. Steel poles will be connected together by an earth-wire.

23. The factor of safety for steel poles will be not less than 6, taking the maximum wind-pressure at 30 lbs. per square foot. In the case of lattice poles the pressure on the lee side will be taken as one-half of the pressure on the windward side.

Arms.

24. The conductors will be carried on insulators mounted singly or in pairs on steel channel arms, or singly upon iron brackets fastened to the poles; or, if wooden arms are used, an earthing strip or stout wire will be fastened on the upper side of each arm. The conductors will be carried singly on short arms or on brackets on poles supporting cradles, in order that the width of the cradles may be reduced.

Road Crossings.

25. Where the line crosses a public road, canal, or railway, the angle between the line and the direction of the road at the place of crossing will not be less than 60°, and the height not less than 25 feet.

26. Where the line crosses a public road, canal, or railway, the wires will be prevented from falling by a wire cradle. When a good earth can be obtained, the cradle will be earthed, and the cross wires will be not more than 4 feet apart. When a good earth cannot be insured, the cradle will be supported by insulators, and the cross wires will be not more than 2 feet apart.

27. An imaginary line drawn from any conductor wire to the top longitudinal wire of the cradle will make an angle of not more than 45° with the horizontal.

28. The cradle will be constructed of galvanized steel wire not less than 7/16 S.W.G., and the span will be as short as possible. Cross stiffeners will be used when necessary.

General.

29. Galvanized-iron wire used for stays, cradles, or other mechanical purposes; galvanized-iron binding-wire; arm-bolts, nuts, and washers; stay-swivels; truss- and brace-rods, and truss-tie, tie and brace bolts; stay-rod tighteners and test-pieces will conform to the British Standard Specification for such material (B.S. Specification for Telegraph Material), so far as that specification is applicable.

30. The work will be carried out, so far as circumstances permit, in accordance with the Post Office Technical Instructions for the Construction of Aerial Lines.

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Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Author, remarked that the Paper was not only valuable in itself, as containing a very large amount of information collected with difficulty from many places, but was also valuable to engineers who had to do with overhead lines, in that it set forth suggestions—non-official suggestions though they were—as to what those lines might be in future, and submitted for frank discussion the outline of a system which the Board of Trade thought of issuing. It was much to the advantage of engineers generally, and to the credit of the Board of Trade that, through the Author, that method had been adopted, and that the system could be discussed from every point of view before it actually became an official set of regulations by which all engineers had to abide.

The Author. The AUTHOR remarked that since the Paper was written English overhead lines had been subjected to severe tests. At the beginning of 1907 there were about 40 miles of overhead line erected, and they had stood the very severe snowstorm at Christmas, 1906, without a single mishap. Since then, 10 to 15 miles more had been erected, which, with lines in process of construction, had weathered the recent very severe gale without a single mishap. He thought that spoke highly for the kind of work that was being done. The Author then exhibited a series of lantern-slides descriptive of existing transmission-lines, and demonstrated upon a model the result of cutting a line carried on flexible poles.

Mr. Merz. Mr. C. H. MERZ remarked that he had had to put down many cables where he would rather have put up overhead lines, partly owing to the difficulty of getting wayleaves, and partly on account of the large number of roads and wires that had to be taken care of in putting up overhead lines. He thought The Institution was greatly indebted to the Author, because the question was a very important one, now that the distribution of power over considerable areas would have to be undertaken. The cost of cables as compared with pole-lines was really about 3 to 1 if any large amount of power had to be conveyed. For long distances a cable might cost £2,000 or £3,000 per mile; so that if pole-lines could be erected on any extensive scale it would mean a large reduction in the capital account, which of course was really the chief question in all problems of power-distribution. With smaller powers the saving was not so

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Mr. Merz. large. That brought him to the most important point in the transmission of electrical energy by overhead wires, namely, that the system was much more suitable for transmission than for distribution. Distribution entailed tapping the wires at different points, which further entailed terminal poles and other expensive arrangements. It might further be deduced that overhead wires would never be used as much in England as abroad, because the distances were so much shorter; in this country it would be always more a question of distributing electrical energy than of transmitting it. At the same time, great saving might be effected by the use of overhead wires. At first sight, when going into the question of taking a transmission-line through a district, it generally appeared that an overhead line should be used, but, on going into the matter further, it would be found that there were many roads to be crossed, there were Post-Office wires in the way, and landlords were difficult; and in many cases overhead lines which at first looked very promising had to be abandoned. Those difficulties in the end increased the price to the consumer, and it was to be hoped that with a Liberal Government in power it might be possible some day to get compulsory wayleaves over private property. The question of steel versus wood had been carefully considered in the work he had carried out, and he agreed with the Author in his preference for wood for all ordinary English lines, although he did not know whether he would agree that the wooden pole would last so much longer than the steel pole. Recently in the neighbourhood of Zürich he had seen some handsome concrete poles, and he thought that was a form of construction which should be carefully considered. The concrete pole was cheaper than the iron pole, it needed no painting, and it was certainly more sightly than a wooden pole. The Author's graphical illustration of the use of flexible poles was very interesting. Mr. Merz did not wish to suggest that the mathematical calculation of the stresses on the poles was not quite a good guide as to what should be done in practice; but he did not know that it quite took into account the jerk which, in the case of a wooden pole, would certainly seem to be the most serious strain that could be put upon it. Sudden breakage of the wires in a span caused a severe jerk to the neighbouring poles, and probably the calculations could hardly be made on the final position which the pole assumed. Guarding was certainly a great trouble, but it had to be done if the line crossed telegraph- and telephone-wires. He hoped that in time the Post Office would meet engineers more than they had done already—and they had been very good in discussing things—in regard to putting the telegraph-lines underground. Certainly, so far as the power-

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companies were concerned they would be very glad to pay any expense incurred, and he thought it must be easier for the Post Office to put their wires underground than for engineers to divert a heavy transmission-line. He understood there were difficulties in the way, from increased capacity due to the wires being turned into cables for short distances; but already telegraph-wires through large towns ran for many miles underground, and therefore it would seem that there could not be much objection to putting them underground for a few additional yards. Mr. Merz.

Mr. JOHN GAVEY observed that his experience related rather to the construction and maintenance of telegraph-wires than to transmission-lines, but the two subjects were so akin that perhaps what was said of one might apply in a measure to the other. He desired first to correct a small error in the Paper which was due to careless editing in his own office. Referring to the second paragraph on p. 187, while both copper and iron wires were erected with a nominal factor of safety of 4, the statement that during a great breakdown a factor of safety equal to about 32 had been reached before the wires broke down, applied to iron wires, not copper. The iron wires used in those days had an elongation, due to ductility and elasticity, of about 10 to 13 per cent. The copper now used by the Post Office had an elongation that did not exceed 1 per cent., and the same data would not apply. With regard to the use of the weight per mile for describing conductors, instead of gauges or diameters, the Post Office adopted the weight per mile before the standard wire-gauge had been formulated, and when every manufacturer had his own wire-gauge. The use of the weight per mile was of considerable service for telegraphs in saving calculation; the weight per mile indicated at once the quantity required, and consequently enabled the cost of railway-carriage and cartage to be quickly determined; and the resistance of the conductor was found roughly by dividing the weight per mile by, for approximate results, the figure 900; or, more accurately, by 875·5, the weight of the ohm-mile. With regard to aluminium, he had had some interesting experience of the use of aluminium wire 7 or 8 years ago, when about 16 miles were put up in the Potteries for telegraphs, in lieu of copper wire. After being up for a few months the wires were broken in every span by the first heavy gale of wind. Sections were tested, and it was found that the tensile strength was practically unimpaired. The wire was repaired and suspended again, and the same thing occurred. The breaking-stress of the original wires varied from 340 lbs. to 365 lbs., and the normal stress with which the wires were suspended was 35 lbs. at the insulator, at 40° F.; and yet Mr. Gavey.

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Mr. Gavey. an ordinary gale of wind broke every span. He thought there must be some unexplained reason for the fact, for even though the wire were blown out at an angle of 45°, it was impossible to conceive that the breaking-stress had been reached. He therefore had some sections brought into the stores and cut into 36-foot lengths, which were hung vertically and weighted. The first section broke at 300 lbs., after ½ hour's stress; the next broke at 280 lbs. after 5 hours; the next at 240 lbs. after 118 hours; the next at 220 lbs. after 525 hours. He thought that pointed to the fact that the failure was due largely to fatigue. He could hardly think it was due to the fatigue of the whole length of the wire; but in the early days there were difficulties in the manufacture, and the wire being probably not of uniform character throughout, the fatigue gradually affected the weaker places and caused fracture at relatively low stresses. He did not wish to dwell on that point, as no doubt the manufacture of aluminium wire had been improved since; he only referred to it because it was a matter to be borne in mind in considering the use of aluminium wire for overhead conductors. He was quite at one with the Author on the absolute necessity for elasticity in structures carrying transmission-lines. He had seen very many cases where accumulations of snow, combined with a gale of wind, had strained heavy telegraph-wires to such a degree that, but for the elasticity of the line, the stretching of the stays, and the yielding of the soil, miles of line would have been blown down which otherwise remained practically intact. They had been a little deformed, but had not cost much to put right. With regard to the causes of breakdown, reference had been made to the factor of safety used by the Post Office. He had never known a case of an extensive breakdown due to wind alone. The causes of breakdown that affected Post Office wires, and would probably affect transmission-lines, were, first, a combination of snow and wind, and, secondly, the falling of trees. When snow fell and the temperature was above the freezing-point, the wet snow adhered to the wires and accumulated till it had attained a diameter of 3 inches or 3½ inches, and under such conditions, if even a moderate gale of wind arose, something had to give way. Heavy gales of wind in the autumn, when the leaves were on the trees, caused many trees to fall, and no line, either for power-transmission or for telegraphs, would withstand such stresses. Another cause, less frequent, might arise in mountainous regions. He had a case in South Wales where the line crossed a hill 1,000 feet high, and every winter the wires came down. Mist and fog were driven across the wires and froze on them until the diameter was

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2 inches to 3½ inches, and then something gave way, either the wires, the arms, the supports, or the poles themselves. He had shortened the spans and increased the sag without effect; either the wires broke or they became twisted in an inextricable mass. He had given it up at last and put the wires underground, although even then he had been beaten, because in the following summer the turf caught fire and burned the cable. He had had cause to consider deeply the best means of guarding ordinary telegraph- and telephone-wires by means of cradles or otherwise, and occasionally he had had doubts as to whether it would be better to earth the cradle or to insulate it. Unquestionably, if an excellent earth could be provided, the proper thing was to earth the cradle; but in chalky or rocky soils the ordinary earth provided on a telegraph-line might vary in resistance from 5 or 10 ohms up to 500 or 600 ohms. If the resistance was high he was afraid the earthed wire itself and the guard would reach a very dangerous voltage and cause damage. Before trusting to the earth being effective, the actual resistance of the earth in all cases should be tested. With regard to Mr. Merz's remark as to placing telegraphs underground, he never hesitated to do so in order to avoid dangers from overhead structures, but the difficulty was with the telephones. At present, owing to the necessity for protecting telephone-wires from tramway and other moderate power-circuits, heat-coils and fuses had to be put in, which very materially increased the resistance of the lines. Between London and Glasgow there were lines which weighed 400 lbs. per mile, and owing to the interposition of the resistances the effective resistance had been reduced to the equivalent of 300 lbs. per mile, or, in other words, 25 per cent. of the speaking-capacity of those wires had been lost. To add the static capacity due to innumerable lengths of underground work would be so serious that he was afraid it might not be possible to ultimately speak over the wires for the distances for which they were provided.

Mr. Gavey.

Mr. E. W. MONKHOUSE observed that he had placed on the wall a stress-strain diagram (*Fig. 24*), for various sizes of hard-drawn ordinary commercial copper, the samples of which had been obtained from the British Insulated Wire Company without telling them what they were to be used for. The diagram showed the results of the testing of some of the samples, taking every other one. The curious thing about the tests was that taking the top bunch of wires, the elastic limit, the limit of proportionality, of all of them, was almost exactly 38,000 lbs. It was not shown very distinctly upon the diagram because there was no very clear limit: it had been found by observing when the elongation began to increase for a

Mr. Monkhouse.

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Mr. Monkhouse. given additional stress. The Author said that a factor of safety of

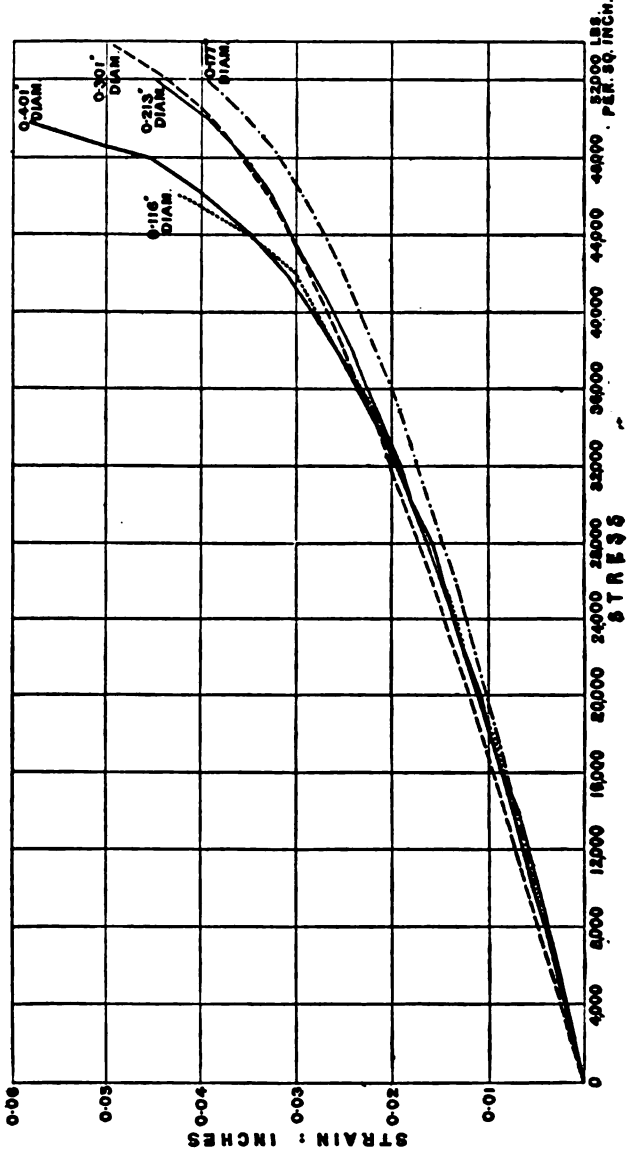

Fig. 24.

about 5 seemed to be reasonable for hard-drawn copper wire, but Mr. Monkhouse would like to know whether the Author proposed

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to take that factor on the limit of elasticity or on the ultimate breaking-load of the particular wire, because it made a great difference. If taken on the elastic limit of wires such as those shown in the diagram it really meant that it was not practicable to hang them up at all, because the poles would be very close together. Mr. Gavey had spoken about the percentage elongation of copper wire, and the Author suggested that not less than 15 per cent. should be specified; and on p. 187 it was said that the Engineering Standards Committee had laid down a certain rule to determine what was meant by hard-drawn copper wire, and had defined it as that which would not elongate more than 1 per cent. without fracture. Was actual elastic elongation or permanent elongation to be taken? If permanent elongation, it was a very difficult thing to get any two wires, or any two specimens of the same size of wire, to give the same permanent elongation. He had some results of measurements made on the same wires that he had used in plotting *Fig. 24*, and taking No. 1 S.W.G., the permanent elongation, exclusive of the fracture, varied from 0·1 per cent. to 0·5 per cent. On a No. 7 S.W.G. wire it varied from 0·6 per cent. to 0·1 per cent. On No. 9 S.W.G. it varied from 0·5 to 0, that was, there was no permanent elongation at all on one specimen. On p. 189 the Author, speaking of wind-pressure, said that the Post-Office practice was to allow 17 lbs. per square foot at a resultant point 22 feet above the ground. He was there talking of wires, but probably he meant it to apply to the calculation for poles, as it did not seem to matter what height above the ground the wire was. Again, the Author said that 30 lbs. per square foot would be a suitable wind-pressure to allow on wires. Mr. Monkhouse had recently had to design a line for a foreign country and had been told to allow 50 lbs., although he thought 30 lbs. was sufficient. With regard to cradles, the regulations, if there were to be any, should be amended, at any rate for abroad. He had just received a regulation which said that the cradle was to be three times the width of the transmission-line. That was not unreasonable when there were only three wires on a pole, but when there were six wires, or nine wires in the form of a pyramid, three wires on the top and six wires below on one bracket, three times the width of the transmission-line was absurd. In the first case the total width of the cradle might be something like 6 feet, but in the other case it would be 16 feet. If 2 feet outside the wires were sufficient in the one case he did not see why it should not be so in the other. The Author suggested that, until some further experience had been gained, work which would not warrant the use of at least No. 7 S.W.G.

Mr. Monkhouse.

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Mr. Monkhouse. had better be carried out by underground cable. That might be so generally, but where expense had to be closely considered it was rather a hard condition. He thought the German rule given on p. 191 with regard to insulation on wires was excellent, because ordinary insulation put on overhead wires for extra-high-tension work was absolutely useless.

Mr. Sparks. Mr. CHARLES P. SPARKS had had no experience of transmission-lines at the pressures mentioned by the Author, but in the last few years he had had experience of distributing on overhead wires at a pressure of 3,000 volts. In a colliery-district in South Wales one scheme of transmission-lines involved about 12 miles of route, or about 45 miles of conductor, and he disagreed with the view that overhead wires were only generally advisable for transmission. In colliery-districts underground cables were a source of great difficulty; there was a creepage going on in the soil, and it was very difficult to prevent cables from being drawn apart or joints from being thrown out, which resulted in frequent failures. The overhead line, at any rate in his experience, had proved quite reliable. With regard to safety, such lines were generally put in isolated positions. In the case he was speaking of, the lines were on private property except where they crossed public roads, and there special precautions were taken with cradles. Several types of cradles had been used, but either the deep U or the box had proved a source of difficulty owing to the wind tending to blow the cradle in contact with the wires. The form shown in *Fig. 11* (p. 203) had proved the most reliable in use. The Author alluded to the cradle being a source of danger owing to the difficulty with snow. Fortunately, with the pressure always on the line, two things tended to keep the transmission-line free; first, the heating of the wire, although slight, was sufficient to prevent accumulation of snow, and secondly, repulsion took place to the drier particles of snow. The risk of failure of the lines was extremely small. Insulator-failures in spans of 40 yards were practically unknown. The only source of danger was the small boy on the public highway. The cross arms supporting insulators should be of metal, earthed. With reference to screens, he preferred the earthed screen to the insulated one. The screen was earthed at each pole by running down a wire which was coiled round the base of the pole. When the lines were first put into use it was found the circuit-breakers at the station were pulled out if the line was connected to the guard-screens earthed in that way. With regard to the size of the wire, he thought the members were much indebted to the Author for *Fig. 3* (p. 190). In his own experience wires between No. 4 and No. 7 had been used solid, and the diagram showed that the limit

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of No. 7 was a safe and practical limit. With a smaller wire the length of the span had to be decreased, which increased the cost of transmission; and he thought it would be found that No. 7 was really a very practicable limit. Above No. 4 all conductors were stranded. The heaviest line he had put up had a cross section of 0·2 square inch, and he had no experience above that. Insulation on overhead wires, he thought, was a source of positive danger and should be prohibited. Another matter which had to be considered in connection with overhead lines was lightning, and with steel masts an overhead earthed wire was necessary. That was a source of some danger, because if the earth-wire broke at any time and fell on transmission-lines it stopped the supply. He himself preferred timber poles, only using steel masts at points of special strain; and in that case there was no necessity to have the earthed overhead wire. The position of the line with reference to the contour of the ground was of great importance. If a transmission-line was taken over the top of a mountain, or a high hill, the chances of the line being struck by lightning were very great, even in winter time; whereas, by keeping well below the brow of the hill the danger was averted. He agreed that transmission-lines should be kept away from trees, because in that way another source of great danger was avoided. Mr. Sparks.

Mr. C. J. GREENE stated that Callender's Cable and Construction Company had put up a large number of overhead lines, and at many points, either for crossing Post-Office wires or for other reasons, they had had to put them underground; and he thought there was little doubt that one of the points of weakness in an overhead system was where contact was made with an underground system. It had been very difficult to get suitable apparatus for making the connection. He exhibited some dividing-boxes which in practice had satisfactorily solved the difficulty. One was a three-phase box, such as had been working for 2 years on 11,000 volts, both in the heat of summer and during the recent severe winter. The three-core cable was brought up the pole in a wrought-iron pipe, and entered the box at the bottom, where the armouring was clamped, so as to take the weight of the cable up the pole. The three cores were then split out inside the box, the whole box was filled with compound, and joined to the three cores were the three leads going out to the three-phase line. The joint to the three-phase line was in every case made of solid trolley-wire, because if it was made of stranded wire there was a likelihood of water running down the strands into the box. Therefore, whether the conductors themselves were stranded or not, a solid wire was always preferred for making this connection. His firm used corrugated high-tension Mr. Greene.

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Mr. Greene. porcelain, which would easily withstand 11,000 volts, and to keep the corrugations dry there was a large high-tension porcelain cap which fitted immediately over. In order to keep the box dry, a small annular space was filled with either compound or sulphur cement, and as a further protection a small disk of spun copper was soldered on to the bottom of the choking-coil, so that there was no danger whatever of water getting inside the box. The leads in every case were coiled round to form the choking-coil between the overhead mains and the underground mains, and, whenever connected to any long length of underground main lightning-arresters, were fitted in parallel. Another form of box shown was for a two-core cable, for connecting a two-phase circuit to a two-phase overhead line. With regard to the insulator, in getting out the scheme the kind of insulator was left, as a rule, to the contractors tendering, and he was inclined to think that consulting engineers should specify the size and type of insulator they required, otherwise contractors were all tendering on different lines. The variation between the standard insulators of British and of foreign manufacture was very wide. For example, for 10,000 volts, the American standard insulator was $4\frac{1}{4}$ inches high by $4\frac{1}{4}$ inches in diameter; the Swedish was 5 inches high by $4\frac{1}{4}$ inches in diameter; the Italian was $5\frac{3}{4}$ inches high by $5\frac{1}{2}$ inches in diameter; and the English was 7 inches high and 7 inches in diameter. He exhibited an insulator which had been working in Lancashire for the last 2 years with very satisfactory results, at 11,000 volts. In addition to the insulator, there was a clip for fastening the transmission-wire on to the insulator. In Post-Office wires he thought the difficulty of binding a wire to the insulator was very small; with heavy transmission-wires varying from 0·1 to 0·2 square inch in section some special means had to be adopted, and the clip seemed to solve the problem fairly well, but not quite. He thought the insulator he showed was capable of much more than 11,000 volts working-pressure, and might be used at any pressure up to 20,000 volts. Every speaker so far had expressed the opinion that wooden poles were essentially the best to use, and he thought probably that with poles it was purely a question of cost. When short spans of 50 yards were used, the wooden pole was essentially the pole to be adopted, and the steel lattice pole was out of the question. It was only at 100 yards span and more that the steel lattice pole was able to hold its own. In the tests made by Messrs. Wade very interesting results had been arrived at, and he believed they had definitely shown what the relative strengths of an A pole and a single pole were, a thing which he did not think could

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have been foretold from theoretical considerations. As he understood the results of the tests, the strength of an **A** pole was about 4½ times that of a single pole of the same diameter at the ground-level, provided the splay of the **A** pole was correct. For commercial purposes it might be taken that, for **A** poles up to 40 feet in length over-all, the ratio of the splay at the ground-level should be about one-eighth of the over-all height of the pole. When the pole was so constructed it was found that to withstand a pull of 400 lbs. at the top with a factor of safety of 10 on an ordinary 32-foot pole, a single pole would require a diameter of about 11½ inches at the ground-level. An **A** pole would be about 7 inches in diameter at the ground-level, and the ratio of cost between the single pole and an **A** pole of equivalent strength was about 2 to 1. With much heavier pulls such as were liable to arise on overhead transmission-lines, say 1000 lbs., the diameter of a single pole at the ground-level would be about 16 inches and of an **A** pole 9½ inches. In that case the ratio of the cost of the single pole to the **A** pole was about 4½ to 1. Therefore with wooden poles the single pole was out of the question and **A** poles would have to be used. In these tests the results were rather unfavourable to the pole, because the pole had been tested in a horizontal position, and the compression member had naturally tended to drop out of the horizontal plane; with the result that the pole showed signs of weakening sooner than it would have done if tested vertically. To overcome the trouble of the buckling of the compression member, he was inclined to think that instead of having the cross-bolt halfway down the pole, as in *Fig. 7*, it would be better to have two light angle-bars, in which case, if the pole tended to twist out of the plane of the paper, the web of one angle-bar would be in compression and the web of the other in tension, and that would resist the tendency of the compression member to buckle. With regard to wind-pressure, the factor of safety specified by the Author was 5 at 22° F. and a wind-pressure of 30 lbs. per square foot. If both the wind-pressure and the temperature were to be specified, a special Table would be required, and he had searched text-books and Post-Office Regulations in vain to find a table which gave variation in wind-pressure with variations in temperature. If a table was used in erecting a line, the working engineer must have not only his thermometer to measure the temperature, but also a wind-gauge to measure the pressure on the wire; otherwise he would not know what tension to put on his dynamometer. Taking the case of a 50-yard span of 0·05-square inch solid hard drawn conductor, in which he assumed the breaking strength to be 25 tons per square inch, which seemed to be a reasonable figure,

Mr. Greene.

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Mr. Greene. on an absolutely calm day there was nothing to be considered beyond the weight of the wire itself, which, in the case under consideration, was approximately 28·8 lbs. With a wind-pressure of 5 lbs. per square foot, which was officially designated as "a very high wind," there was 28·8 lbs. acting vertically downwards, and a horizontal wind-pressure of 9·4 lbs., and the resultant pressure on the span of wire came to 30 lbs.: and so on. When the pressure specified by the Author, 30 lbs. per square foot, was reached, which was the official "hurricane," there was 28·8 lbs. acting vertically downwards, and 56·5 lbs. wind-pressure, the resultant being 63·5 lbs. All tables he had seen took that resultant pressure as the basis on which to work. It was quite evident that the table could be worked to only when the gale was blowing. If the wires were erected on a calm day the tension on the dynamometer had to be reduced in the ratio of 63·5 to 28·8, which gave roughly half the tension on the dynamometer on a calm day. As the force of the wind increased to the degree mentioned, the tension rose to correspond to 63·5 lbs. load, which gave a factor of safety of 10 when the hurricane was blowing. He could not find any table that dealt with that point. On looking through the Post-Office tables he found they allowed a factor of safety of 4 at 22° F., but did not mention anything about wind-pressure. He presumed that factor of safety of 4 was taken on a calm day. If so, when 17 lbs. per square foot was reached, which was the maximum pressure according to the Post Office, the factor of safety dropped down to 1·97, and at 30 lbs. per square foot the factor dropped to 1·25. It would seem, therefore, that a factor of safety of 5 under those conditions was perhaps rather high.

Mr. Hudleston. Mr. F. HUDLESTON pointed out that in a gale causing a pressure of 30 lbs. per square foot a man could not possibly put up a wire.

Mr. Jenkin. Mr. BERNARD M. JENKIN thought that in connection with guarding the overhead wires by earthed cradles it was necessary to take into account the kind of "earth" existing at the generating-station. There were three methods possible: the solid earth at the neutral point of a three-phase system, an earth through a resistance, or no earth at all. The effects in the three cases would be different. In the first case a solid earth to the neutral point at the generating-station would of course produce the maximum effect in the way of a short-circuit current whenever any transmission-wires touched an earthed cradle or an earthed stay-wire, and under those conditions the difficulty of obtaining a good earth at the poles of the transmission-line was very much increased; it was necessary to carry

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a much larger current, and any defect in the earth at the poles would therefore produce a much greater difference of potential along the earth and might give trouble in consequence. If, however, the neutral was earthed through a resistance, the short-circuit current was reduced to probably something like twice the full-load capacity of one transmission-line—to a figure that would open the circuit-breaker and no more. But with the neutral point of the system earthed through a resistance, it meant that when an earth was obtained outside, the other two phases were put to the full pressure away from earth, that was, the generator was strained, not to the normal pressure between the neutral point and the transmission-line, but to the full pressure. With a 10,000-volt transmission the strain on the machine would be 10,000 volts instead of 6,000. If an engineer was prepared to subject his plant to that strain it would almost seem advisable not to have any earth at all at the generating-station. Then the necessity of the return earth-wire no longer existed; for the point at which the transmission-line touched the earthed cradle went to earth potential, and there was no return current to take back to the generating-station, and no risk of a bad earth at the cradle or fault. Mr. Jenkin.

Mr. W. H. PATCHELL agreed that the question of lightning-arresters depended on the earthing at the station, but thought that sufficient attention had not been paid to the resistance put between the lightning-arrester and earth. He had had a good deal of experience with lightning-arresters and had found great trouble in getting a proper form of arrester. He used the horn type, but had been unable to get it satisfactory until one pole was faced with carbon, and then it had been necessary to establish the proper amount of resistance put between the lightning-arrester and earth. Of course in that case he had been dealing not so much with lightning as with surges set up by mishaps in the plant due to faulty handling, and matters of that sort, over which there was sometimes no control. Mr. C. P. Steinmetz, whose authority was second to none on this question, had said lately, before the American Institute of Electrical Engineers, that money spent on lightning-arresters would be better spent in diverting the line to a district where the lightning was not quite so prevalent. The information given in the Paper was of the utmost value and would help the industry greatly in guiding the Board of Trade as to what restrictions should be imposed. There were difficulties which were not always very evident. Mr. Gavey's ground had caught fire in the summer, and Mr. Sparks's ground had slipped. He himself was now putting a transmission-line over ground which he was told was, in places, on Mr. Patchell

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Mr. Patchell. fire all the year round. On the question of gauges, the Standard Wire Gauge gave no information if the gauge-table was lost. The circular mil, which the Author said was a strange American notion, was much too small, but it did give definite information, because if the circular mils of a wire were known its diameter was known. He wished to put in a word for No. 8 gauge, as it had done yeoman service in early electric-lighting days for arc-lighting, and he thought it might come in for transmission-lines. The Author said that joints were taboo as on trolley-wires, but Mr. Patchell did not quite see that the cases were parallel. The great objection to the joint in the trolley-wire was the trolley jumping over it, but that objection did not hold in the case of transmission-lines, and he did not see why a sound mechanical joint should be avoided. The Mexican poles were a good instance of the relative value of wooden poles and steel poles. The engineers responsible for the line had stated that it was impossible to use wooden poles on account of the number required and the cost of freight, and in that particular case it had paid to use long spans and put up steel poles. He might supplement the figures given by the Author in regard to *Fig. 4*. There were 101 miles of the **A** pole with 400-foot spans, and of the **H** pole there were 170 miles with spans up to 1,000 feet. The steel pole was used also on the line to Toronto, where, owing to the troubles with sleet, the span was only 400 feet. That showed the modifications which had to be made in the pole-line on account of climate. On the same line, where the transmission-line met the Niagara power-house, there were three different forms of lightning-arrester. On the question of wooden arms and pins, he had seen pins in Montreal which worked very well in the country, but in railway-yards the insulators arcked over and the pins were charred deeply. That was due simply to the carbon from the locomotives being deposited on the insulators and arms. He thought the question of guards and spacing between wires might be overdone. It seemed fairly well established that the wires swung synchronously, and it was therefore practicable to allow less distance between the wires than would be possible if the wires clashed. Experience in America seemed to show that the wires might be run fairly close together, dependence being placed on their swinging synchronously. The steps taken to guard against breakdowns depended on the job; in some work it was possible to take a risk that was absolutely prohibited in other work. At the same time, the engineer could not be bound to 16-foot cradles or untold distance between the wires. The line from Niagara into Buffalo had been shut down once, though not through the wires blowing together; the patrol found

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two pieces of something black which it was believed had once been two crows who had an altercation from adjoining wires. At the St. Louis Engineering Congress it was stated that one company alone had turned out, in 60,000-volt transforming plant, 971 transformers, aggregating 228,000 kilowatts, with a maximum of 2,500 kilowatts in an individual transformer. A Californian company had upwards of 700 miles working at 50,000 volts pressure. Those figures showed that work could be carried on with what might be termed reliable safety with high-tension overhead transmission. Mr. Patchell.

Mr. Frank Gill observed that he was not quite clear as to the view the Author took of the elasticity of copper wire; on p. 189 he apparently ignored it, but later on, in dealing with the graphical method, elasticity in the wire was apparently allowed for. If the common method of calculating sags and stresses of line-wires (in which no account was taken of the elasticity of the material) were employed, the results were perhaps good enough, and possibly no very great harm was done, but the tables gave no idea as to what was really occurring, and the word "calculation" ought not to be used when these tables were applied. The National Telephone Company had found these tables very unsatisfactory, largely because they led to unduly slack spans, and consequently some attention had been given to the matter. In addition to calculations taking account of elasticity, a number of experimental observations had been made on specially erected wires, and he would give some of the results obtained. *Fig. 25* (p. 236) showed two curves of sag of copper wire, weighing 100 lbs. per mile (0·004914 square inch section), erected at 68½° F. on a span 151 feet long. Curve A gave the sags from the table as usually calculated for a factor of safety of 3 at 20°, and ignoring elasticity. Curve B gave the sags as they actually were at various temperatures on the wire erected in accordance with the table, and showed clearly the actual observations made. The Post-Office instructions quoted by the Author said, concerning the deliberate ignoring of elasticity, that at low temperatures the actual sags would be somewhat greater than those shown in the table. Comparing A and B at 30°, the actual sag was over 60 per cent. more than calculated, the figures being 20·75 inches actual against 12·5 inches calculated. In fact, the two curves had nothing in common except at one temperature, 78°. It was when the tensions in the wire were investigated, however, that the full error made by ignoring elasticity was appreciated. *Fig. 26* showed the tension in a bronze wire weighing 40 lbs. per mile. The calculations were by the usual formulas, ignoring elasticity, the factor of safety being 3 at 20°, and Mr. Gill.

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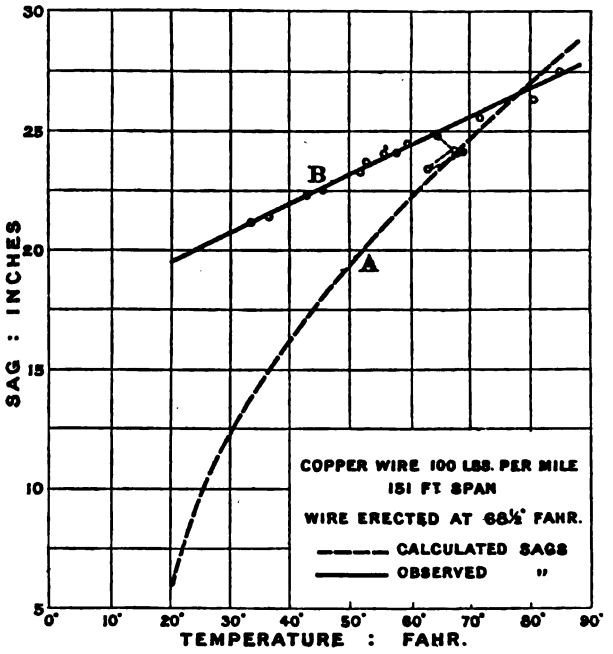
Mr. Gill. the wire was erected on a 151-foot span at 73·25°. A showed the tension which the calculations said would be found, and B showed what was actually observed. At low temperatures the erroneous nature of these calculations was very strongly brought out; at 34° the stress, instead of being 20 lbs., was only 14·5 lbs.; and at 20°, instead of being 66 lbs., one-third of the breaking weight, it was only 15·5 lbs. If now the temperature fell to 10° or lower, the factor of safety having been taken at 3 at 20°, the calculations said

Fig. 25.



that the wire would break, but as deduced from the observations shown on *Fig. 26*, B (there had not been an opportunity of observing lower than 34°), the stress would actually be 16·5 lbs. If any attempt were made by transmission-engineers to carry these misleading figures into the design of the line, and poles and stays were planned accordingly, considerable unnecessary cost would result. There was no reason that he knew of why elasticity should be ignored, and the inclusion of it led not only to a fair approach to accuracy, but also to simplified erection. Professor B. Hopkinson

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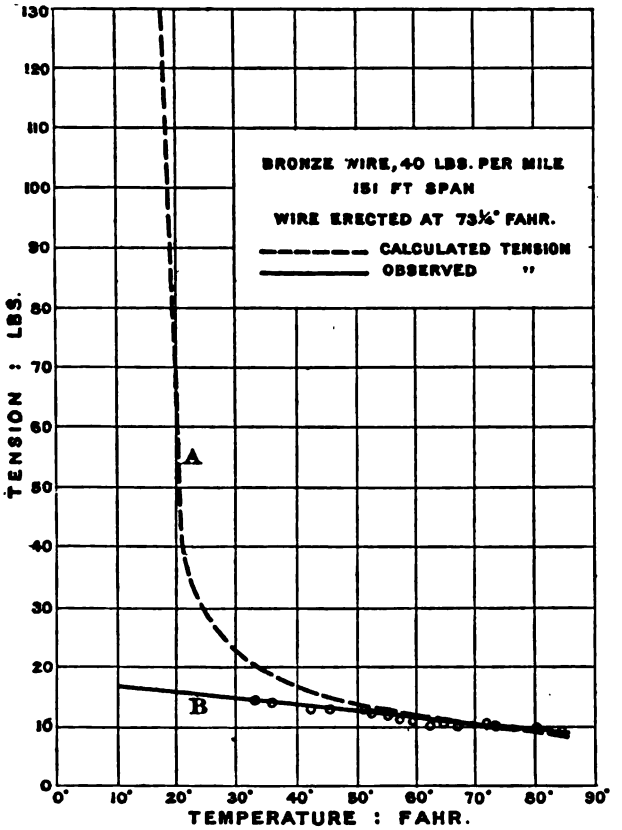
had given [1] a method of calculation, and the following results were based on his formulas, the work having been done by Mr. J. F. Coote of the National Telephone Company. *Fig. 27* showed the sags on two spans of copper wire, 100 lbs. per mile (0·004914 square inch section), erected at 69°, one being 151 feet and the other 256 feet. The calculations included elasticity, and were for a factor of safety of Mr. Gill.

Fig. 26.



3 at 10°. Curve A showed the calculated and B the observed sags on the shorter span; C and D showed the same on the longer span. On the shorter span at 30° the sag as deduced was 1·75 inch more than calculated, the difference varying from 2 inches to 1·25 inch

[1] "Sag and Strain in Trolley-Wires." *The Electrician*, vol. xlvi (1901), p. 501.

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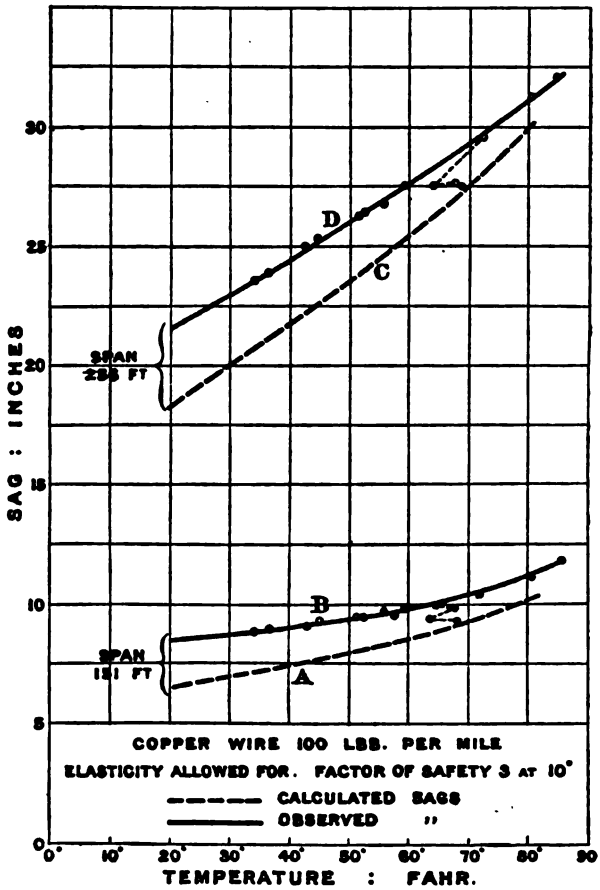
Mr. Gill. between 20° and 60°. On the longer span at 30° the sag was 3 inches more than calculated, and the difference between 20° and 60° varied from 3·25 inches to 2·25 inches. With regard to this difference between the calculated and observed figures, even when elasticity had been allowed for, copper and bronze wires appeared to

Fig. 27.



experience a permanent extension, even when subjected to light loads. In the curves referred to, the first observation made directly the wire had been erected was marked; there were then three or four observations (which were connected to the initial observation by a dotted line showing the chronological order) made

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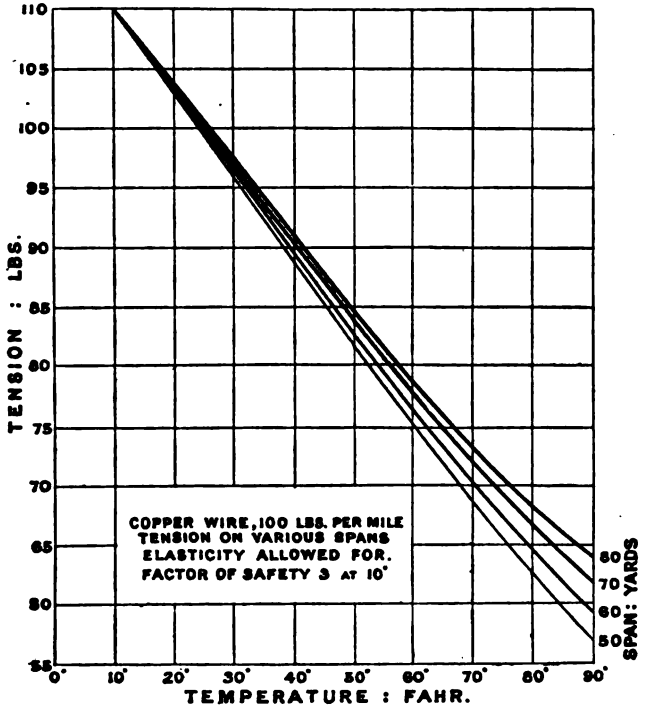
during the stretching period, and after that the wire appeared to settle down to a regular behaviour. So far, this factor had not been brought into the calculation, except by giving it some weight in determining the factor of safety on which to calculate. Allowing for elasticity permitted simplified erection, because practically it ceased to be necessary to pay any attention to the length of the spans. Unless the temperature was very high and the variations in the lengths of the spans very great, the stresses in practical spans were so

Mr. Gill.

Fig. 28.



much alike that all that was necessary was to observe the temperature and pull up the wires to the tension given in the table. The wire was pulled up through a number of spans at one time and permanently bound in afterwards; care was of course necessary that in terminating the wire it was not slacked out below the tension shown on the dynamometer. *Fig. 28* showed the tensions in copper wire weighing 100 lbs. per mile for various temperatures and spans; the difference between the mean and the extreme did

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Mr. Gill. not exceed 3·2 per cent. at 70°, or 4·2 per cent. at 80°. Generally speaking, it was a great deal easier to regulate by tension than by sag; for example, in mountainous country or where there was difference of level, regulation by sag was troublesome, and the tensions given in *Fig. 28* might, he believed, be used with advantage instead of the tables referred to in the Paper. The factor of safety was 3 at 10°, and by projecting the curve to lower temperatures it was seen that the elastic limit of copper, taken at 27,500 lbs. per square inch (135 lbs. for 100-lb. wire), was not reached until the temperature had fallen to about 27° below zero F. Wires erected to these tensions had stood well, and as the Author pointed out, the effect of wind was greater on small than on large wires, so that Mr. Gill thought it would be found that these figures made ample allowance for wind. For copper wires of other weights the tensions were nearly proportional to the weight. With regard to the proposed regulations, he feared that any effort made to include the modulus of elasticity as provided in clause 3 would lead either to expense in special experiments or to erroneous figures being quoted. He had dealt at length with clause 5. He feared that the proposal to have no line-stays on straight runs, as provided in clause 12, would not prove satisfactory. Lines were constantly subjected to sudden stresses, as, for example, when a tree fell on and broke the wires. In the example given at the foot of p. 120, if the six wires were broken at once trouble might arise; but the matter went further than that. A line must be so designed as to face snow and wind, and if owing to both these causes the wires got near their breaking-point and then a breakage of all wires on one side occurred, the poles were almost sure to fall. The telegraph- and telephone-engineer had to decide whether, in the event of the worst conditions, his poles or his wires should be saved, and apparently the same would apply to power-transmission. He was sorry the Author provided nothing for the protection of wires such as those of the National Telephone Company. The method of crossing which appeared to be the most satisfactory was the short-span method, and this was the basis of the Post-Office design illustrated in *Figs. 13.*

The Author. The AUTHOR, in reply, was gratified that the discussion had elicited a good deal of information about the mechanical characteristics of copper wire, but he was not convinced that a wire so hard-drawn as to have an elongation of only 1 per cent. was more advantageous than one having greater ductility and a slightly lower ultimate breaking-strength. Mr. Monkhouse had asked whether it was proposed to take the factor of safety on the limit of elasticity

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or on the ultimate breaking-load. The Author considered that the factor of safety was the ratio The Author.

$$\frac{\text{ultimate breaking-stress}}{\text{maximum normal working-stress}}.$$

He used the word "maximum" here to include the maximum wind-pressure at the minimum temperature (usually taken at 20° F.) and he added the word "normal" to indicate that it did not include a condition of partial wreck or collapse of the line, or extraordinary stress such as that due to a fallen tree. In further reply to the same speaker, the Author, who had had several years' experience of colonial life, deprecated that regulations made for the United Kingdom should be borrowed and applied to colonies and other places abroad where conditions were necessarily different. Mr. Greene had alluded to a pressure of 30 lbs. per square foot as the official "hurricane." A hurricane was defined by the Meteorological Office as a wind having a mean force exceeding 17 lbs. per square foot, or a mean velocity exceeding 75 miles an hour. It was estimated that the extreme velocity of gusts might reach 105 miles per hour, equivalent to 33 lbs. per square foot. Had the Author known when he was preparing the Paper that in Mr. Gill's opinion the ordinary tables gave no idea of what was really occurring, he would have been saved from a considerable amount of useless calculation. He had desisted from this when he was satisfied that the errors or suppressions were on the safe side. Mr. Gill's contribution on this subject appeared to be of great value. On p. 204 "telegraph- or telephone-wires" were mentioned, and the whole of that section was intended to apply to telephone-wires as well as to telegraph-wires, but perhaps more to telephone-wires, since it was often more difficult to place them underground than telegraph-wires.

Correspondence.

Mr. C. H. K. CHAMEN heartily congratulated the Author on the very valuable and exhaustive Paper which he had brought before The Institution. The subject was one on which but few reliable data were available, and those who took part in the discussion were bound to speak of their own experience. He differed somewhat from the Author's conclusion that no overhead wire should be used of a smaller sectional area than 0·024 square inch. If so small a wire had a low tensile strength it must surely be better to decrease the span Mr. Chamen.

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Mr. Chamen. and run an overhead line than to incur the far greater expense of laying it in the ground. He did not agree with the Author's contention that no joints should be allowed in extra-high-tension overhead lines. There was a clamp on the market which possessed the special feature that it was mechanical only and required no soldering: it made a perfectly safe straight through joint, and could be used at terminal poles for making the wire fast round the shackle-insulators. It was of course of the greatest advantage to be able to abolish soldering altogether on overhead lines. He thought that the question of the advantage of having an earthed strip on the cross arms was a very open one. In his experience, while having seen only one case where the wire falling on a cross arm resulted in the burning of the pole and the consequent stoppage of supply, he had seen many cases where the wire got adrift from its insulator, and, although constantly swinging against the wooden arm, caused no damage, and carried the load until a convenient time occurred for its refixing. Had the cross arms been provided with earthed strips in both cases, no damage would have been done to the poles, but in every case the line would have been shut down. As regarded insulated cradles, it was highly necessary to have means of putting the whole thing to earth when required. Especially was this the case when more than one circuit was carried on one line of poles, as it was often necessary to do small repair-work, either upon a dead circuit or upon the cradle itself, while some of the lines were alive. This was always a more or less dangerous job, and with the cradle unearthed the danger would be greatly increased. As regarded insulators, if a wire was allowed to be free in the groove on the top of an insulator, there was a tendency, should the wire elongate from any cause, for the whole of its sag to be concentrated at one point. If a line was run uphill and the wires were not tightly held to the insulators, the span at the foot of the hill would always get more than its share of the sag. As regarded Appendix II, clause 7 seemed to be too strict. It was often convenient and certainly safe to carry an overhead line over the roof of a sub-station and to make joints with conductors which were brought straight down through the roof into the transformer-chamber. The Author had not dealt with the question of sectional isolating switches on overhead lines. It was not pleasant to be up a pole on a dark and windy night disconnecting one circuit while an adjoining one was alive with 10,000 volts.

Prof. Goodman. Professor JOHN GOODMAN stated that the first of the tests of A poles referred to in the Paper were made on A poles of ordinary design, but they failed in nearly all instances through the weakness

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of the top joint. Special attention had therefore been paid to this point, with the result that in new designs this source of weakness was obviated. In the later tests the poles failed, at a considerably higher load than before, through the lateral buckling of the compression-member of the pole, which unfortunately could not be avoided without involving a considerable expenditure of money in providing lateral stays for each pole. The strength of the compression-member could, however, be brought up to a maximum by rigidly holding the two ends; the bottom end was necessarily so held by the concrete or well-rammed earth at the foundation, and the top end could be rendered rigid by a cheap and easily-fitted casting or by some other efficient form of joint. The strength of such an A pole could then be arrived at by calculating the buckling-load of one of the poles by any of the well-known strut-formulas, assuming it to have an effective length of one-half the real length of the pole. The calculated value thus obtained agreed fairly well with actual experiment, but it must not be forgotten that the load on the strut was greater than the load applied to the top of the pole in the ratio of the length of the pole to the width of the structure at the base. The deflection of A poles could also be calculated by assuming that the structure was a simple triangle, the one member of which was subjected to tension and the other to compression. If the top joint was faulty the poles would shear relatively to one another, and the deflection would thereby be increased accordingly. One of the most important constructional questions dealt with by the Author was the wind-pressure that should be assumed to act on the wires and poles: also the factor of safety required to cover contingencies. The Board-of-Trade requirement that poles should be designed for a wind-pressure of 30 lbs. per square foot appeared to Professor Goodman to be excessive for any but very exposed positions. From an examination of many structures in the neighbourhood of Leeds, he found that there were many old roofs and other structures that were certainly not capable of withstanding a wind-pressure of more than 7 or 8 lbs. per square foot; which was a clear indication that they were not, and never had been, subjected to wind-pressures exceeding this amount. It was, however, a matter of common knowledge that in very exposed positions, such as high ground near the sea-coast, pressures greatly in excess of those just mentioned were experienced. The question that naturally suggested itself was—"Is it necessary or desirable to have all overhead poles throughout the country so designed that they shall be strong enough to withstand the excessive wind-pressures only found near the coast?" If the Board of Trade

Prof. Goodman.

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Prof. Goodman. simply drew up regulations for the design of overhead transmission-poles, and took no further action in the matter, it would of course be necessary for them to insist on poles being used which were strong enough for the highest possible wind-pressure experienced in the country; but fortunately for all parties concerned they did take further action in the matter and insisted on all designs being submitted, to be passed by them before the work was put in hand. Was it, then, quite unreasonable to ask them to consider each case on its merits, and to permit smaller poles to be used in sheltered positions than in exposed positions? The high factor of safety for poles, namely 10, insisted on by the Board of Trade had been perfectly reasonable in the past when no one possessed any data as to their strength. The factor was then a factor of ignorance; but now that tolerably exact experimental data were available, and ignorance upon the question was not great, a plea for a smaller factor of safety was justified, and there was good reason to believe that it would still ensure an ample margin against accident to the public. Occasionally telegraph- and telephone-wires did come down in severe storms, but in nearly every instance such accidents had been due to the uprooting of the poles themselves through their not being placed deep enough in the ground. Professor Goodman had made many inquiries upon this question and had only heard of three instances in which the poles themselves had actually broken. In the opinion of those best able to judge, if a little more attention were paid to the foundation of the pole, accidents would be extremely rare, even with the assumed 17 lbs. per square foot wind-pressure and a factor of safety of 8 as adopted by the Post Office. The stress-strain curve for wire given in *Fig. 2* (p. 188) was evidently defective, probably through the experimenter assuming that the elastic line was straight right up to the yield-point. Professor Goodman had made, a short time ago, a series of tests on single and stranded wires for overhead-transmission work and had found in every case that the elastic line was curved, not through kinks in the wire, but through the artificial state of stress common to all hard-drawn wire. Another peculiar feature noted, which was due to the same cause, was that Young's modulus of elasticity was always lower for hard-drawn wire than for the same material in the form of a rod before drawing; it was also found that annealing the wire raised the elastic modulus to its original value, often as much as 15 per cent. The results of this series of tests were extremely interesting, but unfortunately he was not at liberty to publish them.

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Mr. W. A. HARPER observed that up till now the question of overhead transmission-lines had not received in England the same consideration as in the United States or on the Continent. Only quite recently had a few power-companies adopted the system of overhead transmission, and among the first of these was the North Wales Power and Traction Company. As the Author referred to these lines, Mr. Harper, as Consulting Engineer to the Company, and responsible for the design of the transmission-lines, might add to the information about them in the Paper. With the exception of one section on the Nantlle route leading through Llanberis Pass, where steel lattice poles were used for carrying nine wires, only wooden poles had been used, and according to the number of circuits and the nature of the ground there were all the types of construction in use which were mentioned in the Paper in connection with wooden poles. The climatic conditions of the Snowdon district being very unfavourable for any outside work, owing to the excessive rainfall (averaging 180 inches per annum), it was very gratifying that the whole of the lines, about 21 miles in route length, had been put up in 5 months. The country which they traversed was very rugged, the route traversing steep mountain slopes in passing from one vale to another; and special plant, such as tramway-rails, winding-engines, etc., had had to be provided for the cartage of the poles up the hills. Special precaution had been taken to protect the line against lightning-discharges. A number of spark-gaps which had a few hundred ohms connected in series to earth constituted a fairly good method. Many suggestions had been made as to the protection of transmission-lines against lightning and other static discharges, but experience showed that no standard form of apparatus had been developed yet which would prove equally satisfactory in every case. In his opinion the line itself could not very well be protected against the striking of lightning, as the direction which the lightning would take could not be determined. There had been cases where the lightning had struck a line and smashed insulators on about half-a-dozen consecutive poles and charred the side of these poles, whereas a lightning-arrester a few hundred yards away showed no signs of having been in operation. It was of course essential to protect the machinery at each end of the line against possible lightning-discharges, or surges, and he would recommend the use of choking-coils and a number of spark-gaps with series resistances as the best form of protection. A Paper on the subject of protection from lightning had recently been read and discussed before the American

Mr. Harper.

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Mr. Harper. Institute of Electrical Engineers.[1] A suggestion by Mr. Mershon, whereby the system of protection would automatically adjust the resistance of the path to earth to a value necessary to take care of the discharge, was, Mr. Harper thought, worth attention. Supposing that with a given voltage and generating-capacity a horn or other suitable arrester would operate satisfactorily on the assumption that 2,000 ohms were in series with it: Mr. Mershon recommended the use in this case of five such arresters connected to each line-wire, each arrester having 2,000 ohms in series with it. One of the arresters on each wire was set for a low striking electromotive force, another arrester on each wire for a higher striking electromotive force, and so on. Supposing there was a rise of voltage on the line under such conditions that one 2,000-ohm path to earth would properly discharge it, the lowest gap would flash over, and discharge would take place through the 2,000 ohms in series with it, this discharge keeping the electromotive force of the disturbance down below that necessary to strike across the next higher gap. If a disturbance occurred requiring a 1,000-ohm path, the lowest gap would strike, also the next lowest, giving two 2,000-ohm paths in multiple for the discharge. Similarly, with more severe disturbances, more and more of the gaps would flash over, until all five gaps would be active. Mr. Harper had seen this method carried out on the transmission-lines of the Valtellina railways which were built for a working-pressure of 20,000 volts, and where three horn arresters in series were put on each wire having about 1,000 ohms resistance in the earthing circuit. The line had been frequently struck by lightning, and, as far as he was aware, the protection had always been found to be adequate. Another important point in the construction of overhead transmission-lines was the effectiveness of the insulator which was employed. The insulators must be so designed that they did not fail in service. The voltage at which energy could be transmitted depended very largely on the insulators, and, although the highest working-pressure of overhead transmission-lines in this country was only to 11,000 volts, it was well known that there were already 40,000-volt transmission-lines in commercial operation on the Continent, and the voltage of some long-distance transmission-lines in the United States amounted to as much as 60,000 volts. The development of a new type of insulator, which would permit of the raising of the potential, was very important. Messrs. Harpers' chief engineer, Mr. L. F. Szilagyi,

[1] R. P. Jackson, "Recent Investigations of Lightning Protective Apparatus." Transactions Am. Inst. Electrical Engineers, vol. xxv (1906), p. 843.

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who was the designer of the North Wales transmission-lines, had had the opportunity, during a recent visit to Italy, to see a new type of insulator[1] designed by Mr. Guido Semenza, a well-known Italian authority on overhead high-tension transmission-lines. This insulator was provided with an upper petticoat of large diameter to protect the insulator which carried the wires. This upper petticoat, not coming in touch with the wire itself, must not be made of the same insulating material as the proper high-tension insulator which carried the wire. It must only be watertight and sufficiently hard to resist mechanical shocks and rough usage in transportation. It was suggested that it should be made of terra-cotta, which was neither as costly nor as breakable as porcelain or glass. It was claimed that there was a saving of 30 to 40 per cent. for equally safe insulation by using the Semenza insulator with pressures up to 50,000 volts. For higher voltages it was estimated that a saving of 50 per cent. would be effected. The main reason for the excellent performance of this insulator was the fact that the wire was at no time in touch with the stream of water running over the surface of the effective petticoats of the insulator. Taking the climatic conditions of this country into consideration, Mr. Harper believed that in future this type of insulator would find a very large field of application in the construction of overhead transmission-lines. Mr. Harper.

Mr. Henry Jackson observed that the Paper did not admit of much criticism, but referring to the sizes of wires and more particularly their diameters, it was rather unfortunate that the number of a wire in S.W.G. did not coincide with the weight per mile, as it was simpler to refer to the number rather than the weight. He thought the Author scarcely did justice to telegraph-engineers in stating that they know but little of S.W.G. sizes and the corresponding weight per mile. Railway-engineers had been accustomed for many years—in fact, ever since the introduction of hard-drawn copper wire—to speak of the weight and not the gauge of a wire, and most railway companies had given the weight per mile in all contracts for wire for the last 16 years. Aluminium was not likely to be used to any large extent, and it was less likely that iron and steel would ever be used for power-transmission over long distances. There was nothing to recommend the latter except tensile strength, which, of course, was of little account when dealing with copper wires of such diameter as 0·324 inch = No. 0 S.W.G. On p. 189 the Author referred to the advantages of erecting copper lines in summer. If the sag or dip of a Mr. Jackson.

[1] *The Electrical Review*, vol. lix (1906), p. 338.

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Mr. Jackson. wire was regulated in accordance with the temperature at the time of erection, the result should be uniform for any season. It was

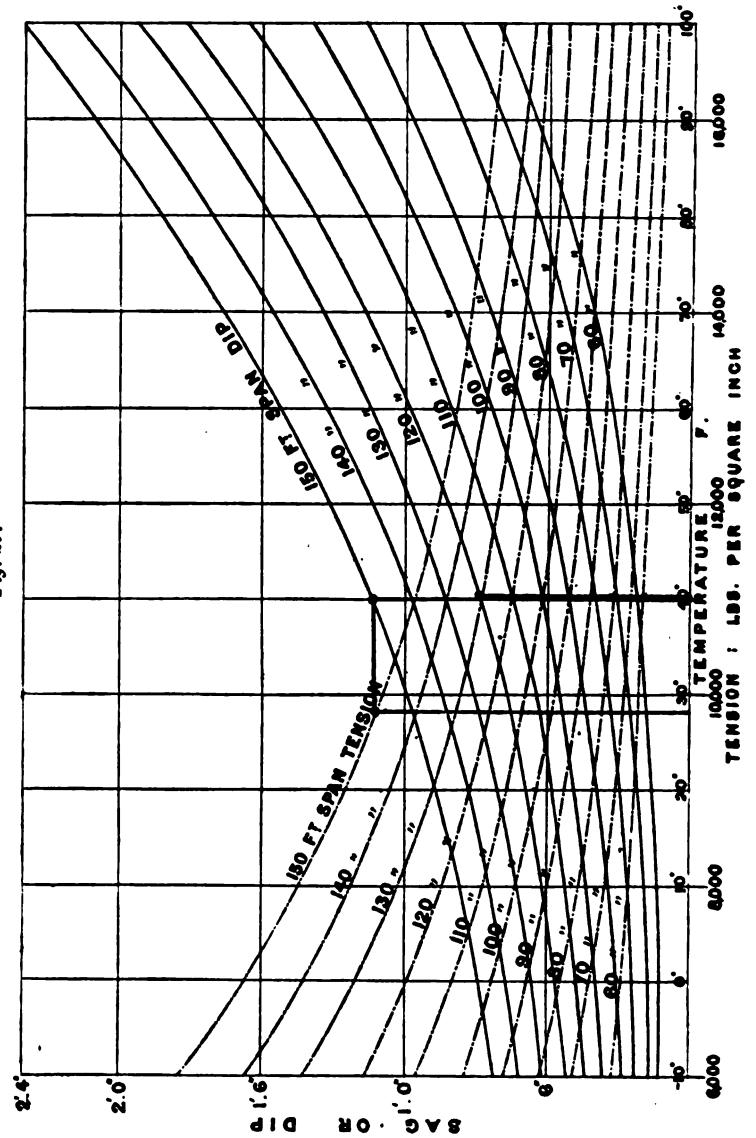

Fig. 29.

customary as regarded railways—and, he believed, the Post Office—for the inspector superintending the erection of wires to carry with

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him a thermometer in order that the wires might be properly regulated with the temperature. The accompanying diagram, *Fig. 29*, would show what the regulation and tensile strain should be at different temperatures. This diagram had been got out in connection with the erection of an aerial power line with conductors weighing 1,678 lbs. per mile. In the case of 50-yard spans at 40° F., taking copper at a breaking-stress of 54,000 lbs. per square inch, the factor of safety was 5·5, and for 40-yard spans 4·88. With regard to binding conductors to the insulators on the straight, clips are, in his opinion, very much to be preferred, and the wires on any curves too severe for clips should be terminated on shackles. Three chains was, he thought, a suitable length for spans on the straight, reduced to about 50 yards where the wires were on a curve. He would have liked the Author to deal more with the static effect of conductors upon metal bodies or conductors in the immediate vicinity of a power-line of 10,000 volts and upwards, and would be glad to learn from him whether any experiments had been made, and if so, what the static current had amounted to. Mr. Jackson.

Mr. J. W. MEARES remarked that, on the question of the factor of safety of posts it was satisfactory to note the proposal to amend the rule at present in force by demanding a factor of 6, the wind-pressure being taken at 30 lbs. per square foot (Par. 23, p. 220). He had had occasion to go into this in connection with a transmission-line in India where tubular Hamilton poles were used. The sections, generally about 8 feet in length, were lettered alphabetically, the smallest being an A tube; and the tubes were so tapered and proportioned that lengthening poles by the addition of tubes below did not appreciably affect their strength. The peculiar fact was elicited that a CDE post, diameter 5¼ inches at the top, and 9¼ inches at base, height 24 feet, if planted in the ground and entirely unloaded, had a factor of safety of only 7½ under a wind pressure assumed at 50 lbs. per square foot, taking the effective surface at 0·66. The rule in force in India at the time demanded a factor of safety of 12 for the whole line under the same wind-pressure, but that rule had been amended since. Tubular poles were unsatisfactory, at least in the tropics. The paint peeled off in the hot weather and its maintenance cost a large sum annually, and a very large amount of heavy staying was necessary. The difficulty of obtaining wayleaves for transmission-lines had been surmounted in India by a section of the Indian Electricity Act, 1903, which in certain cases allowed a company to exercise the powers which the telegraph authority possessed for running lines. In such cases only the right of user was given and no land need be acquired. It was to be feared that this would be impossible in Great Britain. Mr. Meares.

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Mr. Molesworth.

Mr. W. H. MOLESWORTH observed that the Author rightly said "unreasonable excellence of quality and fastidious precautions will simply render overhead electrical transmission impossible." Economical design must be the guiding feature if overhead transmission was to be commercially successful, and the less the designer was hampered by restrictions and hard-and-fast rules the better. Reasonable precautions for the protection of property and the public were essential; so were the factors of safety for wires and supports; but beyond this there should be freedom. Many questions should be decided by circumstances and according to local conditions, and the following remarks on the span, height of wires from ground, and construction of poles would illustrate this. With regard to the height of the lowest wire above the ground, anyone responsible for a transmission-line would endeavour to select a route where wayleaves were cheap, and this meant running the line along the side of a railway or canal, or wherever there was the least traffic. The 500-volt tramway trolley-wires ran at 17 feet above ground-level through crowded thoroughfares, and the reason that accidents were few was that the wire did not break, and not that the voltage was not dangerous to life. On p. 196 it was suggested that the height of the lowest wire above ground be 20 feet. Height did not signify safety but rather the reverse, and 16 feet was generally sufficient to clear anything with safety. In the case of the line being carried along a railway or along other unfrequented routes, Mr. Molesworth thought 16 feet from the ground should certainly be permitted. If the height of the lowest wire above the ground and the maximum dip were decided, it would generally be found that not much was gained in capital cost by employing spans of, say, more than 150 feet: twenty large poles might cost as much as thirty-six smaller ones, but this depended upon what height and quality of pole could be procured cheaply. When, however, the transmission-voltage was really high, say 30,000 volts or more, it was advisable to adopt spans of nearer 300 feet than 100 feet, because the points of support were electrically the weak points of the line and should be reduced as much as possible. The insulation of the line-wires should be maintained wholly by the insulators at high voltages. Metallic pins and cross arms were preferable to wood, but the latter were quite safe for voltages up to, say, 15,000 volts. Continental experience ought to have convinced engineers that pole-construction was satisfactory with a variety of designs, whether rigid or flexible. He had had occasion to study this subject some years ago when the calculations for poles such as that shown in *Figs. 14* were first published. The design was excellent

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because it was cheap and good, but he had never been much impressed by the importance of flexibility. The results of a breakage on a line with only one wire were applicable only to the continuous-current series system. In the majority of long-distance transmission-lines there were six wires per pole or structure, or at the least three; and the pole in *Figs. 14* was designed for six wires or more. Now supposing there were six wires per pole and one wire broke the pole remained rigid because the other five wires were in tension, and in many instances there would be no deflection at all. On any pole where there were only two wires and one wire broke the consequences would be more dangerous if the pole did bend than if it remained rigid. With a proper factor of safety it was not usual for wires to break, and certainly it was very rare where more than one wire broke on the same occasion. He did not, therefore, agree with the Author's statement, that rigidity in poles was a serious defect, because he did not think flexibility had any real advantage in practice. Mr. Molesworth.

Mr. W. C. POPPLEWELL remarked that the Author, in discussing the strength of wires, referred to the use of various factors of safety. This use of such factors made the imposed stresses dependent on the ultimate strength of the wire, and took no account of the relation between the elastic limit and the breaking-strength. The factor of safety was apparently also intended to cover certain indeterminate forces which might at times come upon the wires. Would it not be better to fix upon the maximum stresses that ought to be applied to the wires without any reference to the ultimate strength or to a factor of safety? Experimental work on the elastic and ultimate strength of copper trolley-wire under different conditions was, as the Author pointed out, greatly needed at the present time. It might interest readers of the Paper to mention the results of some experiments upon copper trolley-wire made in the Materials Testing Laboratory of the Manchester Municipal School of Technology. The object of the experiments was to find out how the ductility and strength of trolley-wire were affected by annealing, by wear and tear on the straight run, and by the soldering of the wire on to the ears. The wire tested were that used by the Manchester Corporation Tramways, and the results of the experiments were summarized in the accompanying Table (p. 252). Of the wires tested, A was a length of new wire which had been softened by heating and quenching, B a length of new wire in its hard-drawn state, C a piece which had been soldered under the suspension-ear and been used for about 2 years, while D was a straight length which had been in use for the same time. In the case of Mr. Popplewell.

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Mr. Popplewell.

Specimen.	A.	B.	C.	C.
Initial diameter, inches . . .	0·403	0·404	0·365–0·396	0·374–0·399
,, area of section, sq. in. .	0·127	0·128	0·114	0·117
Maximum load, tons	1·80	2·90	2·50	2·60
Stress at maximum load, tons per sq. in.	14·10	22·60	21·90	22·20
Elongation at maximum load, per cent.	35·20	2·80	1·54	1·49
Elongation after rupture, per cent.	45·80	5·70	4·06	3·50
Limit of proportionality, tons per sq. in. (about) . . .	..	7·80	7·80	6·80
Modulus of elasticity, lbs. per sq. in.	..	16,000,000	16,800,000	17,500,000

the two last it was found that a considerable reduction in the area of cross section had taken place by reason of the wear caused by the trolley-wheel, amounting to about 9 per cent. The differences in the values of the elastic modulus obtained in the three cases might be partly accounted for by the difficulty in ascertaining the true value for the area of cross section. It was found in elastic tests of copper that the limit of proportionality, which was the nearest approach to the true elastic limit obtained in this case, was very difficult to fix with accuracy, as the departure from the elastic condition was very gradual and not so definite as in the case of iron and steel. There was practically no proportional limit in the case of the annealed wire.

Mr. Redman. Mr. S. G. REDMAN observed that there was some difficulty in adhering closely to the factor of safety proposed by the Board of Trade. It was, of course, impossible to erect lines during the worst conditions which the Board of Trade proposed to provide for, and the average linesman would not trouble much about the ordinary winds. Although at the beginning of a job sags were carefully measured, during the bulk of the work the linesman would strain the wire by eye, and to cover the probable errors of judgment on the part of the erector it would be better to specify a wire with a breaking-stress not exceeding, say, 25 tons per square inch, rather than one with a higher breaking-stress and a relatively small elongation. With the softer wire it would be found in practice that where this was slightly overstrained during erection it would, within a short time, permanently elongate so as to provide a sag which would give quite a reasonable factor of safety. He had found this to be particularly so in the case of tramway-conductors; when erected too tightly during warm weather they had stretched slightly

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beyond the elastic limit during the succeeding winter (giving a larger summer sag), but the resulting reduction in tension had taken care of the factor of safety on the span. Obviously it would be extremely unwise to use wire of too low a tensile strength, as the result would be that the lines would require re-straining every spring. This, he believed, had really happened in some of the early overhead tramway-construction in the United States, where particularly soft wire was used. Whilst the factor of safety of 5 suggested by the Author (assuming this was based on the breaking-stress of the wire) could be quite well maintained with short spans, it would result in abnormal sagging with long spans, and would have to be met by spacing the insulators farther apart. For 20,000-volt work, he had considered 3-foot 6-inch spacing sufficient up to 150-foot spans, and if double circuits on A poles were employed any increase of the spacing became unwieldy. It was probably for this reason that braced structures were used largely in America for double-circuit pole-lines. This construction, however, was not nearly so satisfactory as the A pole, and if the factor of safety of, say, 4 were permissible, A poles could be used for longer spans. The life of wooden poles was almost entirely dependent upon the quality of the creosote, and the depth to which this was injected. It was generally specified that 10 lbs. of creosote per cubic foot should be provided, but even assuming that this quantity was used, it must all be concentrated on the outer layers of the pole, as the wood was very seldom impregnated beyond a depth of 1½ inch from the outside, the heart of the wood being practically untreated. His impression was that in England telegraph- and telephone-poles did not have an opportunity of proving their useful life, since the large majority were taken down within 10 or 20 years of their erection, either for the diversion of the lines along more convenient routes, or for carrying the lines at greater heights, or else for increasing the capacity beyond that originally contemplated. It had been stated that A poles gave a ratio of strength to price so much greater than single poles that the use of the latter was hardly admissible. It must be remembered, however, that in many cases, especially where a single circuit was contemplated, and where the route was straight, the great strength of the A pole was often quite unnecessary, and the extra cost was not justified, even although it was only twice that of a single pole. Further, when running alongside wagon-ways, for instance, the extra space required for the A pole was a distinct disadvantage, and in some cases might render wayleaves impossible. With regard to cable-dividing boxes for terminals, he considered

Mr. Redman.

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Mr. Redman. it a great disadvantage to have the bare conductors spaced closely together, especially in view of the very large amount of power that a short-circuit would have behind it on a large system. In order to overcome this difficulty Messrs. Reyrolle and Company had standardized an arrangement by which the conductors were taken from the top of the cable-dividing box by single insulated lead-covered cables, each of which was carried to a point directly below the high-tension overhead line to which it was to be connected, the sealing end being placed at this point. This design permitted the full spacing of bare wires to be maintained and resulted in a neater arrangement. Guarding was at all times a necessary evil in line-construction, and it had been found difficult to make a tidy job of the standard U-shaped cradle under any conditions. It was always liable to be a source of trouble by swaying into contact with the line during high winds, or breaking down under combined conditions of ice, snow, and severe storms. A comparatively neat cradle had been made by using a small aluminium channel section for the stretchers and reducing the longitudinal wires to five. The stretchers were bent round a former before erection and were attached to the heavy longitudinal suspension-wires by mechanical clips. As an alternative to the U-shaped cradle, the County of Durham Electrical Power Distribution Company had submitted a proposal to the Board of Trade for a catenary form of road-guard (*Fig. 30*) which made a more mechanical job. With regard to the difficulties of the Post Office, whilst appreciating the trouble in regard to speaking caused by the cabling of sections of trunk telephone-lines, Mr. Redman would point out that the number of such lines crossed by overhead mains was never likely to be large, and even if the lines were placed underground at all these points, the total mileage would be relatively very small. The small extra cost would seem to be justified, as, no matter how well overhead guarding was carried out, the Post-Office wires were very liable to breakdown, and after fracture the wires might be blown in all sorts of unexpected directions. On the other hand, the power-lines were practically immune from breakdown and yet were debited with the whole cost of all guarding. With regard to the continuous earth-wire, Mr. Redman entirely disagreed with the view that this was not necessary for wooden poles since it was essential in the event of any failure of the conductor itself or of its fixing to the insulators, or the breaking of the insulators, that the earth should be absolutely certain, and this could be effected only by means of a continuous earth-wire of ample section. The Post-Office arrangement of carrying an earth-wire down the pole and coiling it

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under the butt did not seem to meet the case. In the first place, the total area embraced by the earth-coil in the ground was comparatively small; and secondly, the drainage of the creosote from the pole into the ground certainly waterproofed the coil to a certain Mr. Redman.

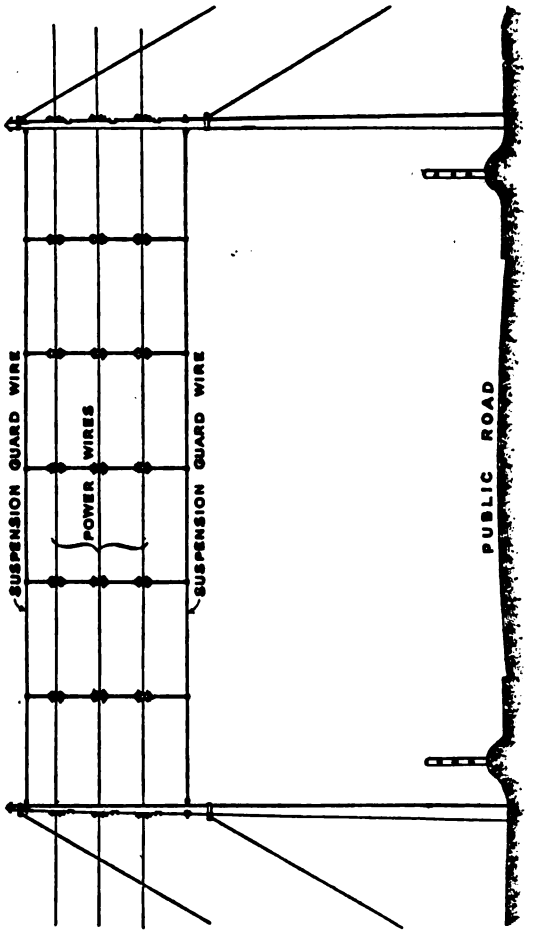

Fig. 30.

extent and rendered even this small area more or less ineffectual. A continuous earth-wire joined to substantial earth-plates at proper intervals, including special provision for these at guard networks, practically ensured a definite earth, even although one or more of the earth-plates in parallel should fail from any cause. He contended

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Mr. Redman. that the whole of the ironwork at the top of the pole should be connected to this earth-wire to prevent the possibility of surface leakage down the pole becoming a source of danger to any person on the ground who might come into contact with the pole. Apart from the desirability of diverting the leakage-currents along a definite path, it also added to the safety of the line. Should any short-circuit take place, the more the resistance in the earth-circuit could be reduced, the smaller would be the burning effect and the possibility of a live wire falling on an earthed wire and burning through it. Given a reasonable earthing-arrangement and efficient cut-outs at both ends of the line, burning effects on high-tension short-circuits were comparatively slight; this was shown to a marked degree in breakdowns of extra-high-tension cables where the fault in most cases consisted of a pin-hole through the insulation, often very difficult to find at all. The continental practice of forming an "earth" by laying radiating copper wires about 2 feet deep in the ground had been found efficient owing to the large area embraced, but as the life of wires in the ground was short, it was better to drive in a number of iron rods and connect these in parallel in a substantial manner.

Mr. Ristori. Mr. E. J. RISTORI, referring to the Author's statement that six or nine wires were generally used for transmission-lines, pointed out that this was due to the fact that the line of three wires used for the transmission of three-phase current was generally duplicated or triplicated so as to avoid any risk of interruption if one line was out of order. There were in use at present several transmission-lines with only four wires. It had been found, after many years' experience, especially in Switzerland, that not more than one of the three wires was ever likely to get out of order at one time, and therefore it had been considered quite sufficient to have only one spare wire instead of three. This was the case especially for private lines, namely, lines used for transmitting energy from a source of supply to a private factory. In the case of a public supply the risks must be reduced to the utmost, and in such cases the lines were all duplicated or triplicated; but for private use the adoption of only four wires appeared to be quite practicable, and, of course, it was more economical. Regarding the causes of trouble in any transmission-line, the experience of many years showed that 90 per cent. at least of the troubles were due to the insulation. For this reason a good many engineers nowadays favoured the adoption of large steel poles and long spans, instead of wooden poles with short spans. In this way the number of insulators was reduced, and consequently the risk of interruption was minimized and the cost of upkeep of the

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line was less. With reference to the use of aluminium instead of copper for transmission-lines, many such lines were now in existence, and some of them had been in operation already for 8 or 10 years. When it was considered that this metal had been produced on a large commercial scale for only about 14 or 15 years, and that therefore its properties could not possibly be as well known as those of copper and other older metals, it must be admitted that the results so far were highly satisfactory. Of course, the purity of the metal, the method of drawing it into wire, and the system of jointing, were a few of the problems connected with its use which would require further investigation with a view to improvements, which no doubt would be forthcoming as the metal became better known. The high price of copper would, no doubt, encourage the use of aluminium for all kinds of electrical work, as this metal, when sold at anything less than £200 per ton, was cheaper than copper at £100 or more per ton. As the price of aluminium had been for many years about £120 to £140 per ton, and there was no reason why it should not be sold at that price again (as soon as the supply of the metal was increased), the economy effected by the use of the lighter metal in the construction of transmission-lines, and in other electrical work where bare conductors were used, would be very considerable. The difficulties mentioned by the Author existed, but they would all be easy to overcome. The experience of the Post Office with aluminium telephone-wires was certainly not encouraging. The breaking of the wires was due chiefly to the greater sag, causing in a gale a wide swinging of the wire until the repeated torsion made the wire break, generally quite close to the poles. Wires for transmission-lines were, of course, much thicker and were not so much affected by the wind. One of the largest and most recent installations of aluminium transmission-lines was one in the South of France, from Marseilles to Ventimiglia. This consisted of a large network of wires distributing the electric energy generated at several central stations (some working with steam and some with water-power) all along the littoral for the use of the tramways, for lighting, and for power in factories. So far these aluminium lines had proved successful.

Mr. Ristori.

Mr. Robertson.

Mr. ROBERT ROBERTSON remarked that the Author had rendered a service, not only to The Institution but also to the profession generally, in bringing the subject forward at this time, when overhead electric transmission was only beginning to receive in England the attention it deserved, and the Board of Trade was to be congratulated upon the manner in which it had dealt with this subject in its pioneer stages. It was in the interest of everyone engaged

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Mr. Robertson. in this work that all reasonable precautions should be taken to ensure the safety of the public, and such a Paper gave a good opportunity for bringing out all the experience which had so far been obtained in England. As Consulting Engineer to the Clyde Valley Electrical Power Company, Mr. Robertson had erected several short lines in that company's district. Most of these lines were on private property, but in two instances public roads were crossed. As the Author had illustrated in *Figs. 6* and *10a* the main features of the design adopted, it was unnecessary to add further particulars. It was interesting, however, to note that since the erection of these lines several very severe storms had been experienced, a wind-velocity of 73 miles per hour having on one occasion been recorded at the Glasgow Observatory, and yet no damage to any of the lines nor interruption of the supply had taken place from this cause. In the construction of these lines a channel 4 inches by 2 inches of British Standard section had been adopted, and this seemed preferable to the size mentioned in the Paper, as it admitted of the insulator-pin being fixed in holes drilled in the flanges and bolted below. On p. 207 reference was made to the danger of a wire falling below the cross arms and making contact with stay-wires. The proposal to use shackle-insulators in the stay did not appear to be altogether satisfactory, and it appeared to Mr. Robertson that it was better to prevent wires from getting off the arms by having a light angle-bar connecting the ends of the cross arms, as indicated in *Fig. 6*. As regarded the relative positions of the conductors and of the upper edge of the cradle at road-crossings, there appeared to be a discrepancy between the remark on p. 200 and clause 27 of the draft model description in Appendix II. It should be made perfectly clear whether it was intended that the top wire of the cradle must be above the level of the conductor at an angle of at least 45° from the horizontal, or might be below the conductor at an angle not exceeding 45° from the horizontal. If it was the latter alternative which was intended, he was of opinion that the protection was insufficient to obviate the possibility of a broken wire getting over the cradle if the effect of wind and possible curling of the wire were taken into account. There appeared to be no disadvantage in having the top wire of the cradle at least equal in height to the highest conductor. Some doubt having been raised as to the stability of an ordinary wooden-pole line in the event of all the wires in one span giving way, Mr. Robertson had had some experiments carried out with a view to determine the effect of such an accident, and the following

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results had been obtained:—Two single poles, selected at random, were fitted with the standard six-wire steel cross-arm construction, adopted by the Clyde Valley Electrical Power Company. Of these, one (A) was set in a block of concrete 5 feet by 5 feet by 3 feet 6 inches deep, the base of the pole being 2 feet 6 inches below the concrete or 6 feet below ground-level, while the other (B) was set in soft ground. Both poles were guyed so as to be vertical under the pull of the wires. The particulars of the poles were the following:— Mr. Robertson

	Pole A.	Pole B.
Depth in ground	6 feet in ground with concrete 5 feet × 5 feet × 3 feet 6 inches deep	6 feet in soft ground.
Diameter at lower cross arm, *i.e.*, 3 feet from top . .	6·9 inches	8·45 inches.
Diameter at 6 feet from butt	8·6 ,,	10·35 ,,
Height above ground to lower wires on insulator . . .	25·2 feet	26·33 feet.
Height above ground to lower wires on insulator to top wires	27·2 ,,	28·33 ,
Mean height above ground to lower insulators . . .	27·26 ,,	
Span	149·33 ,,	

There were six conductors, each of No. 4 S.W.G. hard-drawn copper. The wires were held on the insulators by clips specially designed for the company's lines. Both poles having been properly guyed, the wires were strained up to the following sags:—

Wire. No.	Sag. Feet.	Wire. No.	Sag. Feet.
1	2·22	4	2·21
2	2·02	5	2·12
3	2·12	6	2·27

When the guy at pole A was released the result was that pole A showed a deflection inwards of 9½ inches and pole B a deflection outwards of 2½ inches. The latter was evidently due to the guy rope of pole B stretching under the tension on the conductors and again shrinking when that tension was reduced. The sags were then found to be—

No.	Feet.	No.	Feet.
1	5·54	4	6·07
2	5·57	5	6·39
3	5·82	6	6·22

The guy at pole A was tightened up again till the wires showed approximately the same sags as at starting, the exact figures being—

No.	Feet.	No.	Feet.
1	2·09	4	2·18
2	1·57	5	2·02
3	2·10	6	2·15

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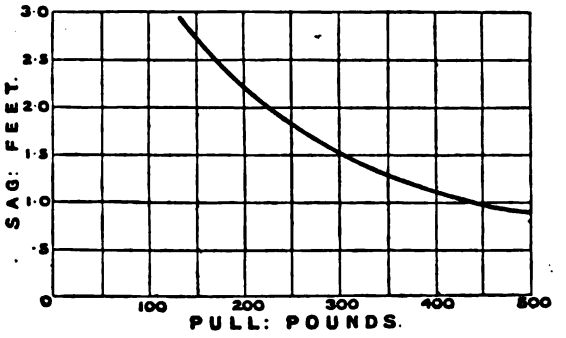
Mr. Robertson. Guy B was then slacked off, when pole B showed deflection inwards of 12½ inches and pole A showed deflection outwards of 2¾ inches. Pole B had a movement of 2½ inches inwards at a point 12 inches above ground-line, showing compression of the earth packed around it, although the poles had been in the ground for 5 weeks before the test was made. These results, having been made on one span only, did not show the same results as would take place if the experimental section had formed a part of an actual line, as the pull due to the guy which was not slacked was reduced immediately the opposite guy was slacked, and therefore did not represent the pull which would be due to successive spans of wire. In order to obtain an approximate idea of the result under actual conditions the tension of the guy at pole B was increased until pole B was pulled over in the outward direction to a maximum of 25¾ inches, with the result that pole A was pulled inwards 17½ inches. The sags with the poles in this position were:—

Wire. No.	Feet.	Wire. No.	Feet.
1	4·3	4	3·85
2	5·25	5	5·50
3	4·05	6	3·81

A test was made on the wire in use, namely, No. 4 S.W.G., to determine the pull at the ends at different sags. The wire was anchored at pole B at a point 3 feet from ground, and passed over a pulley fixed to pole A and attached to a spring-balance. The results were shown

Fig. 31.



on the accompanying curve (*Fig. 31*). Although no actual measurement of the tension had been made with sags as low as the average obtained in the final experiment (4·46 feet), it was evident that the tension per conductor would not exceed 100 lbs., giving a maximum

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total of 600 lbs. for the six conductors. This was so much within the breaking-stress of the poles, as ascertained from the Hull tests, that it appeared that ordinary single poles of the dimensions indicated were quite safe for any stresses likely to come on them in the direction of the line due to complete failure of one span. The figure of 100 lbs. per conductor assumed from the tests agreed closely with the stress calculated by the formula given on p. 189. All the deflections of the pole were measured at the level of the top cross arm. Mr. Robertson.

Mr. HENRY M. SAYERS thought the question of using earthed or insulated guard-cradles had only one safe answer: that was in favour of earthing. It was very important that such a guarding structure should be safe to touch and to work on, and equally important that a broken or fallen live wire should be "dead." Even if the soil was a poor conductor it was not difficult to ensure that any part of it within reach of the cradle or a projecting broken wire was at the same potential as the cradle. That there was a considerable potential difference between it and the station-earth was not an element of personal danger. If the cradle was earthed by a conductor running the whole length of the line to the station-earth, then there was a possibility of shock from the cradle to the soil below. Therefore, whether such an earth-wire was or was not run, the cradles must be earthed locally. The use of a continuous earth-wire was advantageous in ensuring the action of the circuit-breakers when a live wire fell—an important element of safety, since it was conceivable that with bad local earth-connections a broken wire might remain connected, and, although "dead" as long as it remained on the cradle, might be highly dangerous as soon as it was lifted off; or it might, swaying in the wind, saw its way through the cradle by arcking. This seemed to be an unassailable argument for earthing at the station. Dead earthing the star centre of a large alternator was objectionable as giving rise to excessive currents and surging. It was better to earth through a resistance which limited the current, and to cut out the resistance by the use of a circuit-breaker so that the alternator was dead earthed in a second or two. A plate allowed to fall in a tank when released by the circuit-breaker was a simple arrangement, and would give a gradual but rapid earthing which would cause no trouble. Generally the main circuit-breaker would have opened before the plate had reached the bottom of the tank. A cradle made up of longitudinal wires with stiff cross bars or stretchers was greatly to be preferred to any network or lattice using cross wires. The periods of swing of the cradle and of the transmission-lines should be made equal, which was not Mr. Sayers.

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Mr. Sayers. impossible if the cradle-wires were steel, in spite of the loading due to the cross bars; but such equality could not be rigorously maintained with varying temperatures, and ample lateral spacing between cradle and live wires was essential. A great improvement over the cradle was an earthing-bar as shown in *Figs. 12* (p. 204). While a short end might fail to touch the bar, the long end of the broken span was sure to do so, and this sufficed to secure the safety desired. The superior resistance of large wires to storm-stresses was not sufficiently appreciated. *Fig. 3* (p. 190) put it graphically in a quite correct way, but did not show the ratio of resultant stress to breaking-point, which was the important factor. In practice, heavy wires were never broken by direct storm-stresses; this had been repeatedly demonstrated with overhead telephone-cables. During the heavy snowstorms and gales of December, 1906, some overhead work erected to his design on the Wemyss tramways on the Fifeshire coast stood the test perfectly. Part of this line carried five bare copper conductors each of 0·2 square inch section, or a square inch of copper altogether on the poles, in addition to the trolley-wires. But some No. 12 copper telephone- and pilot-wires on the same line were broken in many places by the combined effect of snow and wind. With large conductors it was the poles that had to be calculated for storm-stresses. The calculations about flexible poles were interesting, but it was not quite clear why the Author laid so much stress on the point. Poles on a straight line had no longitudinal stress on them until one or more conductors broke, but they should be strong enough to meet the contingency of taking the whole pull of the wires in one direction without breaking or crippling. Any practicable pole would yield under these conditions, but the greater the yield and the more poles affected by it, the more troublesome would the repair work be, and also the more likelihood would there be of damage to bindings and insulators when the break occurred. He would greatly prefer to use the cheapest pole which would carry the line under normal conditions, and to stay it longitudinally against the pull of the wires in case of breakdown. A pole which bent considerably put very severe stresses on the material at the ground-line. The use of wooden **A** poles was certainly economically correct, and it was a great advantage to have authoritative particulars of their relative strengths and costs, as given by the Author. The general statement that a creosoted pole would outlast three or more steel poles needed some qualification. Setting such poles in concrete was a comparatively new practice, and unless special precautions were taken, decay at the ground-line might be feared. Tubular steel poles could be kept in good external con-

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dition by painting, and, as he had suggested elsewhere, might be thoroughly preserved inside by filling with weak cement mortar. It seemed probable that light steel poles, so filled, might be found highly economical and durable for pole-lines of all sorts, where wooden poles were inadmissible. Mr. Sayers.

Mr. A. M. SILLAR thought that the Paper was exceedingly clear, and treated the whole matter in a practical manner never previously attempted. He was specially interested in the calculated effects of the actual pull on a line of poles when the wires were broken. His firm had made some rough practical trials in order to demonstrate what this pull actually was, and the results obtained were very similar to those of the Author. The Author took the factor of safety of 10 as being advisable in dealing with the side wind-pressure on the pole-line. The latest standard straight-line poles designed for the Lancashire Power Company's overhead routes were 7¼ inches in diameter at the ground-line, and this, worked out on the Author's figure of 30 lbs. per square foot wind-pressure and a coefficient for round surfaces of 0·6, gave a factor of safety of approximately 10; but from practical experiments made Mr. Sillar had always assumed that he could depend on an A pole withstanding fully six times the side pressure of a single pole. While he had not seen Messrs. Wade's results, he thought that this pole should stand this pressure before breaking down to such an extent as to actually give way and let down the lines. The eventual break would probably be in the scarf, and it was possible that the Author's figures were taken at a point before the pole had actually collapsed, but after the scarf was started. These poles had a calculated factor of safety of only 1·3 when all the wires were broken on one side, but no calculation could really take into account the many matters which arose when a breakdown occurred. If it were possible to take into consideration the slip of the wire, the pull on angle-poles, and other matters which had a bearing on the actual result, it would probably be found in practice that the margin of safety was much larger. With the interpretation which he placed on the original Board-of-Trade Regulations, the earlier pole-lines constructed in Lancashire were very much heavier, the diameter at the ground-line of the straight-line pole being 11 inches; yet these only allowed a factor of safety of 2·7 on the present basis of calculation with all lines broken on one side, and he felt sure that the Author would agree with him that these poles were in practice unnecessarily heavy. He would like to ask whether the Author did not consider that a factor of safety of 1 to 1·5 was ample allowance under these conditions. There was only one point in the Paper with which he Mr. Sillar.

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Mr. Sillar. did not agree, and that was the comparison of jointing practice on overhead tramway-lines with that of overhead power-lines. The first necessity on a tramway trolley-wire was that there should be straight under-running and therefore joints must of necessity be on special splicing-ears. On power-lines there was no such necessity, and a properly constructed Britannia joint could be made much stronger than any other portion of the line; moreover it did not need to be heated to such an extent as to weaken it seriously at the ends, as was frequently the case in sweating a heavy metal ear. Joints should be at the poles for preference, but such joints were much sounder than any arrangement of shackling off, shackle-insulators being distinctly a weak point on the system and to be avoided, except for heavy side strains or necessary terminals.

Mr. Wade. Mr. CHRISTOPHER WADE remarked that from the tests he had recently carried out, with the assistance of Professor Goodman, it appeared that single poles of ordinary commercial sizes were of very little, if any, use for this work. The Board-of-Trade Regulations required a factor of safety of 10 after allowing for a wind-pressure of 30 lbs. per square foot on half the area of the poles, and single poles seem to be incapable of withstanding this stress. As it was commercially impracticable to obtain single poles of the necessary size to give the required strength, recourse was naturally had to double ones, of which the **A** pole was much used and very serviceable. This he had shown to be at least four-and-a-half times as strong, at right angles to the wires, as a single pole of equal size, while it had a large amount of elasticity in the direction of the route and a comparatively small deflection across the line. In the line of the wires, the **A** pole had at least the strength of two single poles of equal size, and consequently about half their deflection. Whereas a single pole would deflect, when green, say, 14 or 15 feet before breaking, an **A** pole, while withstanding a load four or five times as great, would deflect only a few inches. To give an example of comparative cost, a line of single poles carrying three wires ½ inch in diameter 25 feet above the ground, allowing 2 feet of pole above the wires with 40-yard spans, would require a pole 32 feet long, if placed 5 feet in the ground. Allowing the required Board-of-Trade wind-pressure and factor of safety, the pole would need to be 12½ inches in diameter at 5 feet from the butt, and each pole would cost £3 3*s*. An **A** pole for the same purpose would require members with a diameter at the same point of only 7½ inches and would cost only £2 2*s*. 6*d*. per double pole, including the necessary preparing, bolts and brace-block, allowing for creosoting the poles in both instances. The most important point in the construction of an **A** pole was the

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method of tying the two members together at the top. This was usually done by bolts passing through both poles, but it might be done by means of a casting or bands.[1] H poles, when properly constructed, were probably as strong as A poles, and had the advantage of giving more surface for attaching wires to; but they were very costly. The cost of overhead lines appeared to be about half that of underground cables,[2] and he believed that good poles, thoroughly creosoted and properly put up, should last as long as, if not longer than, underground cables. With Board-of-Trade Regulations framed to meet modern requirements, it should be possible to make them even cheaper and safer than they were. Steel poles were used in some cases, but their first cost and the additional cost of handling, erection, foundations, painting, etc., seemed to render them unsuitable; while their rapid corrosion, even when properly galvanized, rendered their life a matter of conjecture. Wooden poles of light section appeared to be principally used abroad, and he hoped they would be universally adopted in this country. Mr. Wade.

Mr. CHARLES T. H. WEISS wished to refer to the question of conductors from the manufacturers' point of view. The Author referred to the numerous ways in which the sizes of wires were specified, and it was certain that manufacturers would welcome the advent of one system. Personally he wished the Board of Trade and the Engineering Standards Committee would take their courage in their hands and boldly adopt the metric system. Even consulting engineers had been known to make slips with regard to the gauge of conductors, confounding S.W.G., B.W.G., and B. and S. gauges. He would be sorry to think that the rough trolley-wire, referred to by the Author as little better than rolled rod, was manufactured in England. Copper-wire drawing was to-day a very careful process, and, having been responsible for the manufacture and testing of large quantities of such wire during the past 4 or 5 years, he felt bound to defend English manufacturers. He thought the Standards Committee might have collected more information from copper manufacturers, before drawing up a hard-and-fast definition of hard-drawn wire. In testing, a better method than the measurement of elongation was undoubtedly the "wrapping" test, as used by the Post Office for testing telegraph-wires, that was, the wrapping and unwrapping of a wire several times on its own diameter. This test gave better insight into the internal structure of the wire and the Mr. Weiss.

[1] See Journal of the Institution of Electrical Engineers, vol. 39 (1907), pp. 314 and 315.

[2] P. Dawson, "The 'Engineering' and Electric-Traction Pocket-Book," 4th ed., p. 939. London, 1906.

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Mr. Weiss. character of its manufacture. When the wire was not drawn properly, its strength, as the Author pointed out, was only skin-deep, and the wrapping test revealed the thickness of this skin. As to the strength of joints in the conductor, engineers often specified silver-brazed scarf joints 3 feet in length. This was quite unnecessarily long; in fact, it was much more difficult to make a 3-foot scarf than the usual 6-inch joint. Scores of tensile tests of such 6-inch silver-brazed joints on various sizes of wire had proved that the break did not occur in the joint. He had not tested welded joints as made by some manufacturers, but these should also be as strong as the wire itself. In England, apparently, solid wires, equal to trolley-wire, were favoured for overhead work; in other countries stranded conductors seem to be preferred. The latter certainly were more flexible, easier to erect, and of greater tensile strength. But against these advantages must be set the larger area exposed to wind-pressure, and the slightly higher cost of manufacture. Aluminium conductors had been tried in the United States, apparently not always with success, owing to the exceptionally severe storms which occurred there. The Shawinigan Power Company's lines carried a stranded aluminium conductor ($7 \times 3 \cdot 66$ millimetres); but such a cable might be strengthened by the use of a steel wire core and six slightly larger wires. For the Victoria Falls transmission-line it was proposed to use aluminium stranded conductors from the Falls to the Rand, but the climatic conditions in central Africa were said to be exceptionally good. A sample of this cable, 19 wires of 4·7 millimetres diameter, was to be seen at the offices of the British South Africa Company. The trouble with aluminium conductors would be at the joints. Mechanical joints were generally made; but these would somewhat impair the conductivity. It would be interesting to know whether an electrically-welded cable-joint would not be best. In stranding cables of this metal, single wires frequently broke and had to be joined by electric welding before proceeding with the stranding. It was certainly a good thing for the future of overhead power transmission-lines that there was at the Board of Trade a progressive adviser who came to The Institution asking the views of the members, and also consulted manufacturers before drawing up regulations which all engineers would ultimately have to abide by. In the past, other countries had been able to get ahead of England, as they had not been handicapped by old-fashioned views such as had formerly prevailed at the Board of Trade.

The Author. The AUTHOR, in reply, agreed with Professor Goodman that the locality had an important effect on the maximum wind-pressure,

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The Author.

and he did not think it unreasonable that cases should be considered on their merits. At the present time each case was so considered, and the model description forming the second Appendix to the Paper was intended to invite suggestions. The only difficulty was to make a case by means of maps, etc., without entailing an actual inspection of the route. Mr. Molesworth objected to hard and fast rules, but as a matter of fact there were no official rules at present for high-pressure overhead work. The model description took their place, and the Author would like to postpone as long as possible the conversion of this into a code of regulations. With regard to Mr. Popplewell's suggestion that the maximum stress for a wire should be fixed without any reference to the ultimate strength or to a factor of safety, the Author agreed that the ultimate breaking-stress was not a good quantity upon which to base a rule, for it led to the paradoxical experience of the Post Office mentioned on p. 187; but up to the present, no better one had been proposed. Mr. Popplewell's rule would appear to be that the working-stresses should not exceed a certain maximum. It seemed that different maxima would have to be fixed for different qualities of wire, and it was not clear how the total working-stress was to be ascertained; it was not enough to set down all the stresses that could be predicted; accidents arose from those which could not be foreseen, and there must be a considerable margin. Hence arose the general principle of a factor of safety, which might be disguised, but could not be avoided. The reply to Mr. Robertson's question about cradles was that clause 27 of the model description related to the type of cradle shown in *Fig. 11* of the Paper. The Author did not consider this to be the best type, and agreed that the top wire of the cradle should, if possible, be at least equal in height to the highest conductor. The Author was gratified at having elicited so much information about the mechanical characteristics of copper wire, but much more remained to be known—or at all events to be published—on this subject. The practical nature of the discussion had enabled him to amend the model description in several particulars, and it was not unlikely that further experience would justify other modifications.

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19 March, 1907.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., President, in the Chair.

The discussion upon Mr. A. P. Trotter's Paper on "The Construction of Overhead Electric Transmission-Lines" occupied the evening.

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Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 3670.*)

"Vauxhall Bridge, 1906."

By William Charles Copperthwaite, M. Inst. C.E.

The Vauxhall Bridge spans the River Thames about 1 mile above Westminster Bridge and midway between it and Chelsea Bridge, and is in the direct line of traffic between the western districts of London and the transpontine boroughs of Lambeth, Battersea, Camberwell, and the south-eastern districts of the County of London. It replaces an older structure built in the early years of the nineteenth century on the same site, the demolition of the earlier and smaller bridge having become necessary owing to the great increase of vehicular traffic over it, and to the increasing insecurity of its foundations, due to changed conditions of the river.

Description of the Old Vauxhall Bridge.—Until the commencement of the nineteenth century there were no bridges across the Thames between those of Westminster and Battersea, which were opened respectively in 1750 and 1771; nor does there appear to have been any public necessity for greater facilities than were afforded by the watermen plying at the Vauxhall and neighbouring stairs, for as late as 1820 nearly the whole of the area lying between Vauxhall Bridge Road and Buckingham Palace Road was occupied by osier-beds and gardens, while Vauxhall Gardens were nearly outside the town on the south side of the river.

In 1809 the first Act of Parliament authorizing the construction of a stone bridge across the river, and of a long approach-road on the north side, was passed, and a company was formed to carry out the work. Mr. Rennie was appointed Engineer, and he prepared plans for a stone bridge having eleven arches, each of 60 feet span; the first stone was laid in 1811, but very little actual construction was carried out, the scheme as proposed by Mr. Rennie being abandoned in the same year.

In 1812 another Act of Parliament was obtained, which authorized the construction of a new bridge of iron or other material, and a new

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contract for the work was entered into with Mr. Grellier in November, 1812, the company undertaking to pay him a lump-sum of £72,500 for a complete iron bridge as designed by their Engineer, Sir S. Bentham,[1] the stone-arch design being abandoned.

The construction of the bridge was again proceeded with, but in 1813 the Bridge Company appear to have changed their Engineer, and in consequence some changes were made in the design of the bridge. Mr. James Walker, on taking over the work, prepared a new specification differing but little from that of Sir S. Bentham, save apparently that the width of the spans was slightly altered, and that the method of building the piers was set forth with more exactness. A new contract was made with Mr. Grellier in May, 1813, the total contract amount being raised to £85,613; the bridge was completed, and, with the roadway now known as Vauxhall Bridge Road, was opened to public use in 1816 (Figs. 1, 2 and 3, Plate 4).

The bridge consisted of nine openings, each 78 feet in width, spanned by cast-iron arch-ribs. The abutments were built on grids and piles, and the eight piers, each 13 feet in width, rested on timber platforms on gravel beds. The abutments, and the piers below springing-level, were of coursed masonry with rubble backing, the upper portions of the piers being of brickwork faced at the ends with masonry. It is stated in the specifications attached to the two contracts that the foundations had been tested up to 4 tons per square foot, and it was stipulated that when built each pier should be loaded with a test-load of 1,200 tons. Whether this test was carried out is doubtful; the actual load on the foundations of the highest pier, due to the weight of the pile and of the superstructure, etc., was, however, about 2,230 tons. Allowing for a live load of 120 lbs. per square foot, the pressure on the foundations was therefore 2·8 tons per square foot, or, if the whole area of the timber platform under each pier be taken, and not merely the area under the masonry footings, 1·8 ton per square foot. No movement has ever been noticed in the piers.[2]

The following was the method adopted in building the piers:—Caissons 66 feet in extreme length and 26 feet in width were con-

[1] The Author is indebted to Mr. Frank Stileman, M. Inst. C.E., for the opportunity of reading the original manuscript specifications of Rennie, Bentham, and Walker, a number of reports by the last-named, and Mr. Grellier's two contracts with the Bridge Company. Much of the information relating to the old bridge given in the text is drawn from these documents.

[2] See Report of Arbitration Proceedings: Metropolitan Board of Works *v.* The Vauxhall Bridge Company, 1878.

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structed, and a portion of the footings of the piers, sufficient to ballast the caissons, was built in them before floating them into position. On the site of each pier the river-bed was excavated by dredging to a depth of 3 feet below the proposed level of the masonry foundations, and the trench thus made was filled in with gravel carefully levelled to receive the caisson. So well was this done that when in 1899 these piers were removed the timber platforms were found to be perfectly level. The bottom of each caisson was composed of three layers of timber, having a total thickness of 16 inches, secured with oak treenails 12 inches apart; and the sides consisted of frames of 11-inch timbers covered with 4-inch vertical planking. The side frames were fitted between two timbers running round the bottom of the caisson.

The method of attaching the sides to the bottom, so that when done with they could be removed, is thus described by Mr. Walker:—[1]

"The method of fixing the bottom to the sides is by eighteen pairs of bolts 1½ inch square, the lower ends of which are let into a piece of cast iron with a dove-tail socket which is firmly bolted to the bottom. The lower end of one of each pair of bolts is dove-tailed, the other one is square, both bolts to come about 3 feet above low-water mark, where they pass through a hole cast in a bracket piece of iron which is bolted to the sides. The screw of both bolts is at the upper end, and when the sides are to be disengaged from the bottoms the screw of the square-ended bolt is first turned and the bolt is then drawn out from its bottom socket; by this means the dove-tailed bolt is loosened, and it rises in its turn. The bolts being all loosened the sides float up, and part at the ends."

The internal strutting of the caissons followed the usual practice. The cast-iron arch-ribs were made in three sections, each section being cast in one piece with the spandrel framing above it. Each rib rested on a cast-metal skewback, which was double-ended, extending right across the pier. The thrust of the arches was thus taken by the metal throughout the bridge. The ribs were fixed by erecting simultaneously the end sections of the arches on either side of a pier, and temporarily strapping the upper frames together over the pier so as to form a double cantilever. When two adjacent piers were so fitted the lighter central arch-castings were lifted into place and bolted up. The joints of the castings were not machined, but were caulked with lead and covered with joint-plates bolted to the ribs. When the ribs were erected in place, they were secured by long through-bolts from one face to the other, with muff

[1] Walker's specification, 1813. The cast-iron shoes described were found in place in 1899.

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distance-pieces to tighten the whole structure together, and so keep in position the floor-plates, which were simply flat castings with vertical ribs laid on the upper horizontal members of the main castings. The whole structure of the bridge, when it was removed in 1899, was found to be in good order, and, like most of the bridges of the same period, was very satisfactory from the architectural point of view.

The removal of the old London Bridge in 1831, by the serious alteration which the disappearance of its numerous and massive piers caused in the tidal flow of the river and in the level of its bed, had the same effect on the foundations of Vauxhall Bridge as on those of the old Blackfriars Bridge, and of the still existing Waterloo Bridge. The lowering of the low-water level, which amounted to nearly 4 feet, greatly increased the scour of the ebb-tide, and the bed of the river was cut away to a depth of as much as 6 feet in the portion of the river immediately above London Bridge. The exact amount of the erosion at Vauxhall is not known, but it varied between 3 feet and 6 feet in the central arches, and consequently the footings of several piers were laid bare, and fears were entertained that the underlying ballast would be washed out and that the piers would collapse. From time to time in the next 50 years this scour was remedied by filling in round the piers with iron ore, slag, and other heavy material. This was last done in 1887, and some years later it was found that the protective material had again been washed away. At the same time complaints were raised on the part of the public that neither the width of the bridge—36 feet—nor its approach-gradients—1 in 25 on the north side and 1 in 31 on the Lambeth side—were adequate for the requirements of the road-traffic. The owners of river-craft were equally clamorous on the difficulty of handling vessels in the Vauxhall reach, due to the narrowness of the arches and the disproportionate space occupied by the eight piers, which reduced the waterway by 104 feet, causing the ebb-tide at times to run with a velocity of 7 miles per hour under the bridge. The increase in the number of river-side factories and workshops in the upper reaches of the river in recent years had caused a corresponding increase in the number of craft passing through the bridge, which fully justified the demand for improved waterways, 391 vessels, on an average, going up or down the river every 24 hours.

A proposal was made in 1881 to improve the waterway by removing the two central piers, strengthening the two adjoining ones, and erecting in the gap a bowstring girder-bridge; but fortunately this idea was abandoned. In 1894 the London County

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Council, who, as successors of the Metropolitan Board of Works, to whom the original company had transferred the bridge in 1878, were responsible for its safety, resolved that an entirely new structure on a scale calculated to meet all traffic requirements for many years to come should be built.

The Vauxhall Bridge Act 1895.—In 1895 an Act[1] of Parliament was obtained authorizing the rebuilding of the bridge and the construction of a temporary bridge to accommodate the traffic during the removal of the existing bridge and the building of the new bridge, it being practically obligatory to retain the same site for the new structure. The Act provided that the new bridge should have five openings, and that the centre span should be 155 feet, with a height at the crown above Trinity high-water level (12·5 O.D.) of 20 feet "unless otherwise agreed in writing between the Conservators of the River Thames and the Council." It was finally settled that the centre span should be 149 feet 7 inches with a headway of 20 feet 9 inches (Figs. 4, Plate 4). It was also stipulated that the temporary works in the river in connection with the bridges should be constructed to the reasonable satisfaction of the Conservators' Engineer, "provided that there shall at all times during the construction of the new Vauxhall Bridge be at the site thereof at least three openings each having a clear waterway of 70 feet in width, and one of such openings having a clear headway of 18 feet, and the others of such openings having respectively clear headways of 15 feet above Trinity high water." This clause, limiting as it did the powers of the Conservators by fixing definitely the dimensions of the temporary openings, became, owing apparently to some misunderstanding of its terms, a source of serious trouble. In all matters under the control of the Thames Conservators the Engineers of the bridge have had, as in previous works, the cordial assistance of the Engineer of that body; but with regard to the temporary waterways and headways it was, by the terms of this clause, impossible for him to grant any variation of the dimensions specified. It was also stipulated in the Act that the foundations should be constructed of sufficient depth to allow, should it be found necessary in the future, of dredging the channel of the river to a depth of 35 feet below Trinity high-water level.

After the passing of the Act the construction of the temporary bridge was proceeded with, and this was opened for public use in 1898, the total cost being £38,000. In the meantime the preliminary

[1] London County Council (Vauxhall Bridge) Act, 1895.

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work for the new bridge was commenced and the necessary property acquired.

The conditions laid down in the Act as to the headway to be provided in the central arch, the number of openings required, and the necessity of obtaining a satisfactory gradient from the main roads running parallel to the river on either side, the levels of which could be raised only at enormous expense in acquiring property, practically confined the design of the bridge within very narrow limits. The levels of the road at Vauxhall Cross on the Surrey side, and of Grosvenor Road on the Middlesex side, of the river, are respectively 16·25 and 22·00 O.D.; the level of the soffits of the central arch, or of the underside of the central span, had to be 33·25 O.D.; and allowing 4 feet 6 inches for the depth of construction, the level of the roadway at the centre of the river was fixed at 37·75 O.D., which gave gradients from the Surrey side and the Middlesex side respectively of 1 in 40·75 and 1 in 37·29, with a vertical curve in the centre of the bridge. With these conditions the leading dimensions of the waterways were fixed within narrow limits, and the only matter left to the discretion of the Engineer was the determination of the material of which the bridge should be constructed. Designs were prepared for a granite structure, and later for one of mass-concrete faced with granite, and the latter was only abandoned on account of the difficulty presented by the specific requirements of the Act as to the width and headway of the openings to be provided during construction. These conditions, according to the interpretation placed upon them by the Council's legal advisers, rendered impossible the erection of temporary staging or centering of sufficiently massive construction for the building of masonry arches, and although the advisability of applying to Parliament for a modification of the original Act was considered, it was ultimately decided to build a bridge with abutments and piers of granite and concrete, and a superstructure of steel.

The abandonment of the design for a concrete bridge was a disappointment to all concerned, but in view of the information obtained later by actual excavation as to the nature of the foundations, it was perhaps fortunate that a less heavy type of construction was adopted. It was found when the works were commenced that the material described in the preliminary borings as blue clay was in reality the brown clay composing the upper beds of the London Clay, and that the real blue clay was only to be found at a depth of about −35·00 O.D. to −40·00 O.D., instead of −28·00 O.D., as shown on the borings; and an actual test proved that the brown clay found would have made an unsatisfactory foundation for a structure

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giving (with the usual live load added) a pressure of 4·14 tons per square foot beneath the river-piers.[1]

A commencement had, however, been made with the foundations of the bridge before the design of the steel superstructure was finally settled, and certain of the protective piling-works were made capable of serving as centering piles, in case a masonry arched structure should be finally resolved on.

Description of the New Bridge.—The total length of the new bridge, between the abutments, is 760 feet and the total waterway is 699 feet 4 inches, the two central piers being each 15 feet 8 inches and the two intermediate piers each 14 feet 8 inches in width at the level of Trinity high water (12·50 O.D.). The central span is 149 feet 7 inches, with a headway of 20 feet 9 inches above high-water level; the two intermediate spans are 144 feet 4¾ inches, with headways of 19 feet; and the shore-spans are 130 feet 5¾ inches, with headways of 14 feet 11 inches. The width of the bridge between the parapets is 80 feet, divided into a carriage-way 50 feet in width and two footways each 15 feet in width (Figs. 4, Plate 4).

The gradients of the roadway are 1 in 40·75 from the Surrey side and 1 in 37·29 from the Middlesex side, the central portion being constructed to a vertical curve of 7,559 feet radius.

The abutments are formed, as to the foundations—which on the Surrey side go down to a depth of −17·00 feet only, and on the Westminster side rest on a grid of piles at −20·00 feet—of solid masses of 8-to-1 Portland-cement concrete cased in sheet-piling measuring from front to back 56 feet, and on the face 104 feet 9 inches. At a level of −2·25 there is a set-back of 4 feet 3 inches in the face and 2 feet 3 inches at the sides, and above this level the masonry consists of 6-to-1 concrete faced with the whitest grey granite, fine-axed on the face, in courses of about 2 feet in depth, and set in 1-to-1 mortar of granite-sand and cement, the blocks being secured by groutnicks and slate dowels. The faces are made with a batter of 1 in 10 up to 13·75 O.D., and at this level there is a moulded course or cornice, above which the steel skewbacks of the arches project. The remainder of the front and sides is vertical. The upper portion of the masonry is treated differently on the two abutments, that on the Westminster side having, above the road-level, two massive piers or blocks of granite masonry on each side, destined to serve as the bases either of lofty pylons, or of groups of statuary. These measure 20 feet in length by 10 feet 8 inches in

[1] The area of the cutwater foundations is not included in the effective area of support in estimating this pressure.

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width, and behind them the parapets of the abutment are formed of granite walls 12 feet in height, pierced by arches, across which are built open balustrades. The Lambeth abutment has similar piers, but behind the down-stream pier is an open balustrade and a flight of steps giving access to the foreshore, while on the up-stream side is a plain granite parapet-wall, which is continued some distance along the approach to the bridge. The construction of this abutment involved the diversion of the two large storm-relief sewers known as the Clapham and Effra sewers. The dead load on both abutments amounts to about 2·65 tons per square foot on the foundations.

The piers (Figs. 4, Plate 4) are built on similar foundations of 8-to-1 concrete, 37 feet and 38 feet in width and 140 feet 9 inches and 142 feet 6 inches in length over all in the side and central piers respectively. These foundations are cased in tongued-and-grooved sheet-piling, being the lower portions of the piles of the dams used in constructing them, which were left in when the dams were removed. The levels of the foundations varied between −27·00 and −29·50 O.D., the material beneath being in all cases strong brown clay. As the total load on the pier-foundation,[1] including a live load of 120 lbs. per square foot over the whole area of the superstructure, would amount only to 2·59 tons per square foot on the clay, and to 2·35 tons per square foot if the dead load only were taken, it was considered unnecessary to carry the foundations lower, more especially as some rough tests were made of the supporting-power of the foundations by loading a small area up to about 4 tons per square foot. At an earlier date some tests were made of the supporting-power of piles driven into the brown clay, with the result that 26 tons was considered to be a perfectly safe load on a pile driven down to −35·00 O.D., in the event of centering being required for the bridge.

When a concrete or masonry bridge was contemplated, the advisability of driving piles over the whole area of the abutments and piers was also considered, and plans were prepared with this intention; but although this was done in the case of the Westminster abutment, it was not considered necessary elsewhere. In the case of the Westminster abutment there was a special reason for the piling, owing to the fact that the abutment of the old bridge, which occupied a part of the site of the new bridge, was found to have a grid of piles beneath it, and the driving of new

[1] The area of the cutwater foundations is not included in the effective area of support.

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piles over the rest of the foundation of the new abutment was a reasonable precaution against unequal settlement.[1] In the result, no settlement has so far been observed in any of the piers or abutments. The 8-to-1 concrete foundations of the piers are brought up to a level of −22·50, above which 6-to-1 concrete is used. Above the foundations the piers, commencing with a width of 32 feet, are battered so as to be only 24 feet 2 inches in width at a level of −14·25, above which they have a curved face up to 9·25 O.D. The granite facing commences at −10·25, and is similar in character to that of the abutments. The piers are all alike, except that the centre piers are 1 foot wider than the others, and 2 feet higher, to suit the gradients of the bridge. Their ends are finished with cutwaters, capped with curved granite blocks, and the granite facing below the skewbacks of the arches terminates in a moulded cornice similar to that on the abutments, Figs. 8, Plate 5.

The main feature in the design of the bridge is that the masonry of the piers is not carried up above the level of the skewbacks, their upper portions being simply steel frames faced at either end with plain plate facings in which are sunk panels for the reception of bronze statues of heroic size. By this arrangement the steel superstructure is continuous from one end of the bridge to the other, and it is considered that this gives a more satisfactory effect from the æsthetic point of view than the usual practice of separating the steel arches by carrying up the masonry piers to the parapet-level. In designing the steelwork, the avoidance of all ornament, save such as forms a part of the structural design of the bridge, was kept steadily in view, and no attempt was made to disguise the fact that the arches are of built steel by covering them over with a facia of cast-metal. In all that pertains to the artistic treatment of the engineering design, the Engineer had the advantage of the co-operation of Mr. W. E. Riley, the Superintending Architect of the London County Council.

The superstructure of the bridge is constructed entirely of steel and iron, and consists of five arches, each formed of thirteen ribs bearing on steel skewbacks built into the abutments or resting on the piers. The steel-plate decking, where it does not rest directly on the ribs, or on the steel framing of the piers, is carried on longitudinal joists supported on stanchions also formed of rolled joists, standing on the ribs. All the steel employed, with the exception

[1] Some interesting information as to loads on London clay is given in a Paper on "The Foundations of the River Piers of the Tower Bridge," by G. E. W. Cruttwell, Minutes of Proceedings Inst. C.E., vol. cxiii, p. 117.

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of some small joists, is open-hearth acid steel, having a tensile breaking-strength of not less than 28 tons, nor more than 32 tons per square inch, with an elongation of 20 per cent. in a length of 10 inches. The rivet-steel has a tensile strength of 24 to 28 tons per square inch. The actual stress due to dead load in the main ribs of the central arch, the widest one, is 3·13 tons per square inch, and if the live load be taken at 120 lbs. per square foot the stress due to that would be 1·33 ton per square inch. The maximum stress in the ribs, therefore, with the arch loaded from end to end, would be 4·46 tons per square inch. The skewbacks for the arch-ribs, both in the abutments and on the piers, are of steel. Those in the abutments are 10 feet in length, and consist of two $\frac{3}{4}$-inch plates, 1 foot 3 inches apart, having at one end planed plates to receive the cast-steel hinges and at the back a $\frac{3}{4}$-inch base-plate 5 feet 6 inches by 3 feet 6 inches, the whole being built together with angle-bars 6 inches by 4 inches by $\frac{5}{8}$ inch. They are built into the concrete of the abutment, the concrete being carefully brought up round and in them in thin layers, and each layer being grouted up to ensure complete solidity. Behind the skewbacks and about 4 feet from the base-plates and parallel to them, old steel rails about 18 feet in length are built into the abutment, on end, with the view of distributing the thrust of the arch-ribs over as large an area as possible. The skewbacks on the piers are double-ended, and extend the full width of the pier, on which they rest above the moulded granite cornice, Figs. 8, Plate 5. Each consists of a plate box, 4 feet 6 inches in height and 1 foot 3 inches in width inside, having sides $\frac{3}{4}$ inch and the top and bottom $\frac{1}{2}$ inch in thickness, the ends being inclined to suit the springing of the ribs, and all being framed together by angle-bars $4\frac{1}{2}$ inches by $4\frac{1}{2}$ inches by $\frac{5}{8}$ inch. Behind the end plates forming the skewbacks are two gussets between the side plates, and when fixed the inside is filled with fine concrete and carefully grouted up. The skewbacks are braced to one another by plate diaphragms, and to prevent the risk of any movement during the erection of the arch-ribs, each skewback is anchored to the pier by six 2-inch holding-down bolts, and for the same purpose a vertical plate is fixed transversely under the bottom plate. On the end plates of all the skewbacks a plate, 1 inch in thickness and planed, is fixed to receive the cast-steel hinge of the rib, any adjustment that might be required when fixing the rib being done by varying the thickness of the planed plate at the end of the latter.

The steel structure forming the upper portion of each pier can be best described as consisting of a series of frames built on the skewbacks, and bound together by horizontal and diagonal bracing.

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Each frame consists of two stanchions, each consisting of two pairs of angle-bars, 4½ inches by 3½ inches, with a plate, 12 inches by ½ inch, on the outside pair, gussets being inserted between the angle-bars, to which the cross-bracing of the frame, consisting of angle-bars, 6 inches by 4 inches by ⅝ inch, is attached. On the top of each stanchion is a bearing-plate 2 feet in length by 1 foot in width, on which the main longitudinal joists carrying the decking rest, those immediately above the pier being riveted to the plate, whilst the ends of those of the adjoining arch resting on it are free to move so as to allow for expansion and contraction due to changes of temperature. The frames are secured together at their ends (or along the faces of each pier), by two horizontal girders on the outside, that at the top being a rolled channel, 12 inches by 3½ inches by ½ inch, and the bottom one a 12-inch plate stiffened with two angle-bars 3½ inches by 3½ inches by ½ inch. At the top are also two horizontal angle-bars, 6 inches by 4 inches by ⅝ inch, one on the inner face of each stanchion. There are also cross diagonal angle-bar braces, 4½ inches by 3½ inches by ½ inch, secured by junction-plates both to the stanchions of adjoining frames and to the horizontal girder just mentioned. There are thirteen of these frames on each pier, corresponding to the number of skewbacks, and in addition there is at the end of each pier, forming the upper part of its face, a built frame of steel plates, extending from the bottom of the skewbacks to the top of the parapet of the bridge, and secured by bracing to the adjoining frame on the outside skewback.

The design of the steelwork in the ribs and superstructure is the same in all the five arches, the only variations being those due to the varying spans and headways, and to the different heights of the roadway above, owing to the gradients, Figs. 6 and 7, Plate 4, and Figs. 9 and 10, Plate 5. Of the thirteen ribs in each arch, eleven are alike, the two outer ribs being somewhat lighter to allow of them showing under the projecting plinth of the parapet. These outer ribs are 2 feet 9 inches in depth throughout their entire length, the others varying between 3 feet 6 inches and 4 feet in depth. All the ribs bear at their ends on hinges formed of cast-steel bearings, with a forged-steel pin 9 inches in diameter between them (Figs. 11, Plate 5). The maximum pressure on these pins, assuming a live load of 120 lbs. per square foot over all the bridge, would be 1·68 ton per square inch. The ribs and the bracing between them, as well as that forming the spandrels, are of the ordinary construction. The decking, however, owing to the necessity of allowing a depth of about 2 feet 6 inches under the roadway at the centre for the conduits of the electric tramways, to the space required for the cantilevers

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supporting the projecting cornice under the parapet, which forms an important feature in the external appearance of the bridge, and to the necessity at the same time of keeping the dead load as small as possible, is not uniform in character either transversely or longitudinally (Figs. 6, Plate 4, and Figs. 9, Plate 5). For a width of 12 feet 11 inches in the centre of the bridge, under the lines of the electric tramway, the deck-plates are below the top of the main longitudinal stringers (joists 12 inches by 6 inches, weighing 54 lbs. per lineal foot), to which they are secured by angle-bars, and between which there are fixed joists, 8 inches by 6 inches, 4 feet apart, also supporting the deck. In the centre of each span, in order to obtain the necessary depth for the tramway-conduits, these plates are placed between the main arch-ribs, the diaphragms between which, placed 5 feet 2 inches apart, serve as cross girders carrying the deck. In order to reduce the amount of concrete under the wood paving, the remainder of the decking under the carriageway is raised above that in the centre by placing it on transverse joists, 8 inches by 6 inches, resting on the main longitudinal stringers. The deck-plates in this case are mostly curved, but at the centre of each span, where they are laid on the top flange of the main ribs and supported alternately on plate-diaphragms and channel-bars between the ribs, they are flat. All the deck-plates are $\frac{7}{16}$ inch in thickness. Under the footways the decking is arranged, as in the centre of the roadway, to allow of the fixing of the cantilevers which bear on the outside rib or on the stringer above it, and are anchored to the next rib or to the corresponding stringer. These cantilevers project about 3 feet 6 inches beyond the centre of the outside rib, and the lower flanges are curved at the end to fit the curved plate, which they support, forming the cornice of the face. They also support the longitudinal stringers on which the parapet is built. The space under the footways, where not occupied by these cantilevers, is reserved for pipes and mains of various kinds.

The parapet, or rather screen, for the actual handrail is only 4 feet above the pavement-level, is of special design, being about 8 feet in height, the object aimed at being to increase, when viewed from the river, the apparent depth of construction of the bridge at the point where flat arches constructed in metal have usually an appearance of weakness, namely, at the crown (Figs. 4 and 6, Plate 4). The great width of the roadway also appears to require a somewhat more conspicuous framing than is given by the usual parapet of about 3 feet 6 inches in height.

Removal of the Old Bridge.—It was considered advisable, in view of the urgent public necessity of opening the new bridge at the

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earliest possible date, to make a beginning with the foundations of the abutments and piers without waiting for the complete elaboration of the plans of the superstructure, the main dimensions of which were, however, as already stated, fixed within narrow limits by the headways and gradients required. With this object, the work was divided into two contracts, the first including the removal of the old bridge and the construction of the masonry of the new bridge up to a level of 9·75 O.D., and the second the completion of the bridge above that level. The contractors for the two divisions of the work were respectively Messrs. Pethick Brothers and Mr. C. Wall.

Work was begun in September, 1898, and by April, 1899, the whole of the superstructure of the old bridge had been removed. The removal of the old abutments offered no difficulty, as they were enclosed in the timber dams necessary for the construction of the new abutments, nor did the clearing away of the piers next adjoining them (numbered 1 and 8 in Fig. 5, Plate 4) give any trouble, as the foundations of these were accessible at low water, and they were too far in-shore to interfere with the river-traffic. But the six remaining piers presented serious difficulties owing to the necessity of conforming to the stipulations of the Act, and to the regulations which the Conservators of the Thames, in the exercise of their undoubted right, felt it their duty to lay down for the protection of vessels passing up and down the river. Owing to these causes, the piers were not all removed until the end of 1901; indeed, one pier, which was on the site of one of the larger new piers, was not removed until the dam for the latter was built in the spring of 1902. It was hoped that the piers could be removed without the necessity of constructing dams round them; but after some attempts had been made to break up the old material by the use of small dynamite cartridges, which failed owing to the solidity of the masonry and to the limitation imposed on the amount of explosive to be used at a time, it was found necessary to provide round every pier a small water-tight coffer-dam within which the work of breaking it up could be carried on at all stages of the tide. This method of procedure, involving protection-works occupying about 40 feet of the river at each pier, rendered it impossible to work simultaneously at all the piers without too greatly curtailing the waterway for vessels, and consequently had the result of seriously retarding the work.

The relative positions of the piers of the old and the new bridges, and the areas occupied by the protective works round them, are shown in Fig. 5, Plate 4. It will be seen that the requirement of

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the Act that there should be at all times three waterways each 70 feet in width through the bridge-works, if strictly interpreted, not only precluded the possibility of proceeding with the construction of the new bridge before the removal of the old piers, but practically necessitated the removal of most of the old piers one at a time. The contractors had commenced work on the new abutments and one of the piers before they were aware of the extent to which temporary erections would be required for the removal of the old piers, and perhaps had they known at first of the restriction which the maintenance of the river-traffic imposed on them, they might, by completely removing the old bridge before commencing the new one, have in the end saved both time and money. Considering all the circumstances of the case, there does not appear to have been any serious ground for the complaints which from time to time were made in the public press of unnecessary delay on the part of the engineers and contractors.

The coffer-dams for removing the old piers were whole-tide dams, the tops of the piles being at a minimum level of 17·00 O.D. The piles of the dams were 12 inches by 12 inches, and were not grooved and tongued, the joints being caulked only. The dams were about 73 feet by 30 feet in inside measurements. On each side they were protected from passing craft by a "railing" of 12-inch piles, 7 feet apart, having a 12-inch sill on top. The dams were further protected at each end by a similar railing and by a triangular dolphin, to which floating booms were secured, the protective works measuring 150 feet from end to end, and 40 feet across.

Construction of the New Bridge.—The works of the Westminster and Lambeth abutments were commenced early in 1899, those of the Lambeth intermediate pier in September of the same year, and those of the Westminster intermediate pier in January, 1900. The two central piers, for the reasons already given, were not commenced until the end of 1901, when the piers of the old bridge had been removed. The Lambeth abutment-foundations were got in without incident, but at the Westminster abutment considerable alterations from the original plans were necessary. The borings taken before work was commenced indicated that blue clay was to be found at −20·00 O.D., but at this level only a brown clay of moderate tenacity was found, and water came in under the dam at the down-stream corner, flooding the excavation, the piles having been driven down to about −24·00 O.D. only. As a new boring showed that there was no change in the clay above −40·00 O.D., and as it was found in getting to the bottom of the old abutment, which occupied part of the site of the new one, that it had rested on piles,

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it was resolved to pile over the remaining area of the new abutments, the piles under the old work being cut off at the required level, and this was done, the piles being driven to a depth of about −40·00 O.D.

The temporary works for the piers were of the same character throughout, the only variations being in the details of the walings and framing of the protective dolphins. For each pier a dam, 142 feet 6 inches in length and 38 feet in width, was constructed, the piles forming it being cut off, when the pier was built, at the line of the top of the concrete base, round which the ends left in formed a timber casing. These were grooved-and-tongued pitch-pine, or in some cases Oregon piles, 14 inches square, the tongues being of hard wood, 4 inches by 2 inches, spiked into the groove of one pile and making a close fit with the next. They were driven to depths varying between −35·00 O.D. and about −40·00 O.D., their tops being not lower than 18·00 O.D., the highest recorded tide at Vauxhall being about 16·50 O.D. The frames were on the usual lines, and in the dams first constructed were put in every 7 feet from the top. Later, the spacing was reduced to 6 feet, and in the Westminster central pier dam the lower frames were much closer still. The protective works round each dam are shown in Fig. 12, Plate 5. They consisted of a series of timber dolphins of three types (marked respectively A, B, and C in Fig. 12, and shown in detail in Figs. 13, Plate 5), which at first were connected by floating booms only, as shown in Fig. 12, round the Westminster intermediate pier, but later the booms along the fronts between the end triangular dolphins A and the side dolphins B were replaced by framings to which half-timber diagonal walings, about 2 feet apart, were secured, as shown around the Westminster central pier. Between the pair of dolphins on either side of the coffer-dam floating booms were placed, giving a protected area about 80 feet in length and 22 feet in breadth, one of these areas usually serving as a lay-by for barges during the excavation of the pier-foundations, and both having staging for cranes, etc., erected over them. In some cases, when the pier had been built up to a level of 9·75 O.D., and the coffer-dam had been removed, these side booms were replaced by piles, with the view of at once giving greater security to the works, and of providing a foundation for the centering which would have been required had the original design of a concrete bridge been carried out. This arrangement is also shown in Fig. 12, Plate 5, as carried out round the Westminster intermediate pier. For the conveyance of material from the shores to the piers a cable-way was provided, and at each dam temporary platforms were

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provided, on which were mounted crane-roads, and on which the concrete-mixer was erected.

It is unnecessary to describe separately in detail the work of constructing the several coffer-dams and piers, but a description of the Westminster central pier dam, owing to the numerous mishaps which occurred to it, ending in a complete collapse of one side, and of the successful manner in which it was finally made secure enough to allow of the construction of the pier within it, may be of interest.

Westminster Central Pier Dam.—At the Westminster central pier, the river-bed is at a level of about −12·00 O.D. and is composed of about 2 feet thickness of ballast resting on brown clay which extends to a depth of about −35·00 to −40·00, O.D. (Fig. 15, Plate 5). The construction of the dam was begun on the 9th January, 1902, and the last of the sheeting-piles was driven on the 22nd March. The piles were, on an average, about 53 feet in length, the tops standing about 18 feet above, and the bottoms 34 feet to 38 feet below Ordnance Datum, being driven not less than 20 feet in the clay. For the inlet and egress of the water two valves were provided, one at each end of the dam. These valves were of the sluice type, 12 inches in diameter, and were operated by handles and screws placed outside the dam. The valve at the up-stream end of the dam was placed at a level of −3·25 O.D., and that at the down-stream end at −2·75 O.D., the level in each case being that of the bottom of the inlet. For removing the water in the dam below this level a 15-inch centrifugal pump was placed in the up-stream end, steam being supplied from a boiler erected on the dam. The top frame of strutting was commenced at a level of 15·25 O.D., whole-timber walings being bolted to the inside and outside of the dam-piles. Longitudinally the dam was divided into twelve compartments by vertical frames of strutting, whole-timber struts being placed across the dam between the walings. These struts were wedged up tight between the walings with folding wedges. Between these cross struts were placed whole timbers running the whole length of the dam. The ends of the dam were strutted with whole timbers, which were wedged up to the central line of struts. The general arrangement of the strutting is shown in Figs. 14 and 15, Plate 5. In the cross frames, whole-timber diagonal struts were placed between the top and second frames, and between the second and third frames, as shown in Fig. 15. The top frame was further strengthened and held together by a series of 1¼-inch wrought-iron tie-rods, one alongside each of the cross struts. On the top of the dam two standard-gauge crane-roads were constructed, one for a 3-ton crane and the other for a 2-ton crane. The

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longitudinal timbers carrying the rails were laid on cross timbers stretching across the dam and resting on the dam-piles. These cross timbers were strutted up from below as much as possible during the construction of the pier. The second and third frames of strutting were similar to the top frame, walings being bolted to the dam-piles both inside and outside. The fourth and fifth frames were similar to those above, but the outside waling was omitted, and the inside waling was attached to the piles with coach-screws. On the 30th April the work of taking out the mud from the dam was begun. This was finished by the 5th May, and the excavation in the clay was then commenced. The sixth frame of strutting, and part of the seventh, had been placed in position, when on the 4th June a "blow" occurred at the down-stream end of the dam, on the Westminster side. The blow seems to have occurred near the bottom of the shoulder-pile at F, Fig. 14, Plate 5. On the 9th June a diver was sent down to try to locate the blow, and he found a depression in the river-bed at this point. With the object of stopping the leak, puddle was placed in bags on the bed of the river, outside the dam, round the part of the dam where the blow had occurred. Pumping was commenced on the 10th June, but on the 13th June the water came in again. On again examining the outside of the dam it was found that the clay-bags had disappeared and that some of them had been carried down under the piles into the dam. It was then decided to drive a row of piles round the outside of the dam at this place, and to fill the space between them and the dam-piles with puddle. On the 30th June the driving of these piles was commenced, and on the 25th July the last of the forty-four piles was driven. The piles were tongued and grooved, and averaged about 60 feet in length. Their tops were at a level of about 19·00 O.D., and they were driven to about −41·00 O.D., or 5 to 6 feet below the dam-piles. The dam-piles at this place suffered great injury from the driving of the outer row of piles, being driven inwards at the bottom. At the sixth and seventh frames the walings were burst and the piles were driven inwards 2 or 3 feet. The excavation at this time was at a level of about −25·00 O.D. over the whole area of the dam. The seventh frame of strutting was incomplete at the up-stream end of the dam, and this no doubt allowed considerable movement of the piles. The 15-inch centrifugal pump was replaced in the down-stream end of the dam on the 26th July. On the 28th July the small dam at the down-stream end of the dam was filled with puddle to a level of about 11·00 O.D., the puddle being thrown down on the river-bed. On the 31st July pumping was commenced with the 15-inch pump,

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but it did not work satisfactorily, and on the next day the water was pumped from the down-stream end. At this end of the dam were placed a 4-inch pulsometer and a 4-inch Tangye pump, these pumps having been provided for draining the dam during the excavation of the clay. On the 4th August the water gained 6 feet on the two small pumps, and it was found that a blow had occurred on the Lambeth side of the down-stream end of the dam, opposite the blow of the 5th June, Fig. 14, Plate 5. To try to stop the water coming into the dam, some of the dam piles were dollied down 7 or 8 feet; these piles went down very easily. In addition, ten new piles were driven inside the dam at this point. The driving of these piles round the down-stream end of the dam undoubtedly put a severe strain on the framing of the dam generally. Several of the walings of the lower frames were broken, and some of the main cross struts were badly bent. No doubt also the main piles of the dam, having greater freedom of movement due to the partial weakening of the frames, worked loose in the clay; the seventh frame being incomplete, and the part of it that had been put in not having been entirely made secure, when the water came in the dam would be practically unsupported on the inside for a height of about 10 feet above the level of the excavation. On the 7th August the diver examined the bottom and found a big leak between the shoulder-pile and the first end pile, as indicated at K in Fig. 14. On the 28th August concrete in bags was placed on the bed of the river outside the dam. On the 30th August the valves in the dam were closed, and the water rose 2 feet in the course of one tide, the caulking of the piles having become considerably loosened by their having been dollied down. The piles were re-caulked, and on the 1st September the water rose about 6 inches in 3 hours, with no pumps at work. On the 2nd September pumping was commenced with the 15-inch centrifugal pump at the up-stream end of the dam. This pump was able to lower the water by about 6 inches in 9 minutes, but the boiler proved insufficient to keep the pump at work for more then 10 to 15 minutes at a time. On the 3rd September, ashes were put down outside the dam, where the blow occurred. A good deal of water was coming in at this end of the dam, apparently through the piles. On the next day the diver discovered a split waling in the seventh frame of strutting, as indicated at G in Fig. 14, but there was no sign of water coming under the piles. The two small pumps sufficed to lower the water by about 9 inches in 2½ hours.

On the 5th September the dam burst, at about 4.30 A.M., it being then nearly high water. The level of the tide was about 14·20 O.D., or about 2 feet above Trinity high-water mark. The failure occurred

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on the Westminster side of the dam, about seventeen piles being broken, most of them in two places. The centre of the opening thus made was opposite the last strut put in in the incomplete seventh frame. The walings and struts were smashed in all directions, many of the struts in the lower frames collapsing in the middle of their length. The bolts connecting the walings to the piles were in many cases pulled clean through the outside walings and the piles, the washers being crumpled up and dragged through the bolt-holes along with the bolts. These washers were only $\frac{3}{16}$ inch to $\frac{1}{4}$ inch in thickness. The bursting of the dam caused both sides to be considerably out of line. A diver was sent down to examine the breach in the dam, and discovered that the first of the seventeen broken piles, counting from the down-stream end, was broken, but held on to its tongue. The second was broken off and leant inwards about 6 feet at the top of the broken end, and the third pile was missing. The remaining fourteen piles were broken off and their stumps remained in the ground, leaning inwards, the clay outside having apparently a very straight and good face.

On the 8th September the plant was cleared off the dam, and the damaged timber was further examined; it was found that the walings in the fourth, fifth, and sixth frames of strutting were broken, and that the waling in the seventh frame was missing. This examination was made in the third bay from the up-stream end of the dam. The following week was occupied in clearing away the broken timber, and then work was stopped pending a decision as to the course to be adopted in reconstructing the dam. On the 27th October, after further examinations by the diver, the work of reconstructing the dam was commenced. It was decided to dolly down as many as possible of the piles which remained sound, and to drive new piles a few feet inside the dam to act as vertical members for the new framings to replace those broken. The new piles were on an average about 52 feet in length, the tops being at a level of 11·00 O.D., and the bottoms at −41·00 O.D. They were driven just inside the walings and the new frames butted against them, packing-pieces being inserted between the old and the new walings in the lower frames. Meanwhile the damaged piles on the Westminster side of the dam were being drawn, an additional pile-engine having been obtained in order to expedite the work. On the 9th December the last damaged pile was drawn from the Westminster side of the dam, and walings were fixed in the breach preparatory to driving the new dam-piles.

The new sheeting-piles, forty-four in number, and shown in Figs. 16, 17, and 18, Plate 6, were 60 feet to 70 feet in length, their tops being driven to a level of about 18·00 O.D. and their bottoms

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to between −42·00 and −52·00 O.D. Meanwhile, as many as possible of the piles in the other parts of the dam were dollied down for 2 or 3 feet, until their tops were flush with the walings of the first frame of strutting. They were mostly in the Lambeth side of the dam and round the up-stream end. Light puddle-boxes were attached to the tops of these piles, boards being nailed inside and outside to the piles which had not been dollied down, and the space between the boards was filled in with clay-puddle. By this means the whole of the dam was brought up to a level of 18·00 O.D.

In order to enable the above-mentioned piles to be dollied down, it was necessary to remove the walings in the lower frames of strutting. This was attended with some difficulty as the dam had become filled with mud and slurry to the level of the fifth frame of strutting. The coach-screws in the walings of the fifth frame were removed first, and it was then decided to try to send the diver down through the soft mud until he could reach the sixth frame. For this purpose the diver was furnished with a short length of wrought-iron pipe, 2 inches in diameter, perforated at one end, the other end being attached to a steam boiler by a length of flexible hose. The perforated end had 96 holes, ¼ inch in diameter, drilled in the sides of the pipe, the end being plugged up. The other end was attached by a suitable coupling to the steam-pipe, and was fitted with suitable handles, steam-cocks, etc. The diver worked the pipe round and round himself and, with the aid of steam at a pressure of about 80 lbs. per square inch from the boiler, was able to descend with comparative ease to the sixth frame of strutting. With the aid of the steam-nozzle he was able to work his way round the sixth frame and to remove all the coach-screws. He failed, however, to reach the seventh frame, owing to the stiffness of the mud. As soon as the piles had been dollied down a start was made on the re-strutting of the dam. The first and second frames were repaired wherever possible, and new timbers were added where necessary. The third frame was more damaged than the two frames above it, and after the new timber was put in it was further strengthened and held together by 1¼-inch wrought-iron tie-bolts, one being placed alongside each cross strut as in the top frame.

On the 11th February, 1903, the engine for the 15-inch centrifugal pump was got into position, and the pump was brought round from the up-stream end of the dam to the Westminster side, near where the breach had occurred. The pump was placed over the sump indicated in Fig. 20, Plate 6. On the 17th February the pump was started, but could not keep down the water. At this time the carpenters were at work on the fourth frame of strutting. On the

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20th February, after repeated failures to keep down the water, an attempt was made to caulk the dam by throwing ashes into the river outside the dam at low water. The ashes came through the dam with the rising tide in the two bays on the up-stream side of the big pump, showing that the piles were leaking at that place. On the 23rd February a diver was sent down to try to locate the leakage. He found that the tongue of one of the new piles on the Westminster side of the dam had been split, evidently at the time the pile was driven, and that the pile had run inside the dam, leaving a space between itself and the next pile. This space was about 5½ inches in width at the bottom and tapered to nothing 7 feet higher. This space would of course admit an immense volume of water, with which the pumps would be quite unable to cope. In order to stop this leak as much as possible a piece of half-timber was fixed as a temporary measure against the defective pile, so as to cover the space between it and the next pile (Figs. 16 and 19, Plate 6). Frequent attempts were made to pump out the water in the dam, but the 15-inch centrifugal pump failed to work satisfactorily, rarely running more than "half-bore," and sometimes even less. On the 2nd March a new 12-inch Gwynne centrifugal pump was fixed in the next bay to the old pump on the up-stream side. On the 17th March the new pump was running and the water was lowered to the mud in a short time. The mud, as already stated, was at the level of the fifth frame of strutting, some 14 feet of mud having been deposited since the dam burst on the 5th September, 1902. It was decided to put the new fifth frame 1 foot higher, resting the new walings on what remained of the old timber. This arrangement was also carried out with the sixth frame. The water was never shut completely out of the dam during this time, but was always allowed to rise to the third or fourth frame at high water, so as not to put any undue strain upon the dam. On the 11th March the dam was again flooded at night, water coming in under the patch placed outside the defective new pile. The two big pumps when running together were unable to cope with the inrush of water, and it was decided to drive a half-pile, 18 inches by 9 inches, outside the defective pile. The outside walings were cut, as indicated in Fig. 19, Plate 5, to allow this pile to pass through them, and half-timbers were bolted outside to strengthen them. By the 18th March the leak was to a large extent stopped, and the carpenters were at work again re-strutting the fifth frame. As soon as the fifth frame was completed the mud was taken in skips of about ¾ cubic yard capacity. About 150 skips of mud were taken out in a shift of about 10 hours. On the 7th April the sixth frame of

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strutting was completed, 8 days after the completion of the fifth frame. On the 9th April the leak near the defective pile again gave trouble, and on the 12th April the diver went down outside the dam and found a large hollow in the river-bed near where the leak had occurred. This was due to the scouring action of the tide flowing through the breach in the dam during the last few months of 1902. The diver filled in this hole as far as possible with clay-puddle, and on the 20th April the seventh frame of strutting was completed. On the following day the leak appeared to be much worse, and it was decided to drive a second 18-inch by 9-inch pile outside the dam, close to the defective pile. This second pile is shown in Figs. 16 and 19, Plate 6. In addition to the second half-pile a small puddle-dam was driven outside the defective pile. This dam was driven with 4-inch runners attached to the stage-piles and walings of the dam as shown in Fig. 19. The runners were driven about 6 feet into the bed of the river, and the space between them and the dam was filled with clay-puddle. This was well trodden and rammed and was the means of practically stopping the leakage near the defective pile. The clay-puddle was brought up to about low-water level. After this the 4-inch pulsometer in the down-stream end of the dam was able to keep the water down, except for an hour or two at high water, when the 12-inch centrifugal pump was run for a short while. The carpenters were then able to complete the eighth frame of strutting. This frame is shown in Fig. 17, Plate 6. Double walings were used round nearly the whole of the dam, and the strutting was carefully put in, being selected almost entirely from new timber. In order to test the nature and strength of the clay a trial-hole was excavated and timbered to a level of −28·00 O.D. After examination of the bottom it was decided to take out the whole of the excavation to a level of −29·00 to −30·00 O.D., the clay to be taken out in small pits and trenches. The arrangement and order of taking out the clay in the trenches is shown in Fig. 20, Plate 6. The first portions were taken out on either side of the sump. When these were concreted, 6-inch circular stoneware pipes were laid on the bottom, close up to the dam-piles. These were laid with loose joints so as to collect the water which leaked through the joints in the dam piles. Owing to the shifting and working of the dam, a considerable quantity of water leaked through the piles, and by means of these pipes was drained down to the sump, below the 12-inch centrifugal pump. The masonry-work of the pier was then proceeded with without further incident, and the dam was removed.

The work comprised in the first contract should have been

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completed by March, 1901, but owing to the circumstances already narrated, it was not finished until the end of 1903; when the second contract was let, the coffer-dams surrounding the piers had been removed, but those of the abutments and all the protective dolphins, etc., in the river remained, and were not removed until later. This second contract should have been completed in 2 years, and in fact was finished in 2 years and 4 months. The remainder of the masonry of the piers, and that of the abutments to the level of the steel skewbacks, was first completed. When the masonry of the piers was completed, the erection of the skewbacks on them, and of the steel frames above, which formed the upper portions of the piers, made rapid progress. The fixing of the steel skewbacks in the abutments took some time, as in order to ensure perfect bedding the concrete round them was put in in shallow layers, and carefully grouted up. These skewbacks once in, the abutments were carried a little higher to ensure sufficient weight before the thrust of the ribs came upon them, and the upper portions were finished later. The erection of the steel ribs was carried out in the usual manner, and the only condition imposed by the Engineer during their fixing (beyond those laid down in the Act) was that no pier should ever have to support an unbalanced thrust of more than three ribs. This was a necessary precaution, not only on account of the narrowness of the piers, but also in view of the fact that the skewbacks on them were not built into the masonry but rested upon it. Each skewback was anchored down by six foundation-bolts, 2 inches in diameter and 6 feet in length, and as an additional security had fixed under its base-plate a transverse vertical fin which was imbedded in the concrete of the pier. These fastenings were quite sufficient to resist the unbalanced thrust of an unloaded rib; but it was not desirable that unequal loading of the pier should continue longer than was absolutely necessary.

The erection of the ribs in the two shore-spans presented no difficulty, as these two waterways were not used by the river-craft and further were furnished with the heavy piles fixed in the earlier part of the contract. Stages therefore were easily fixed, and frames erected on them, on which the ribs which were brought to the site in six sections could be erected. In these spans, as in all the others, the hinges were first put in place, the outer or rib casting of the hinge being held in place to receive the butt-end of the rib by light steel bars, which secured it to the skewback-hinge by small set-screws (Fig. 22, Plate 6). When the three central ribs in the two shore-spans were in place, the three central ribs of the intermediate and central spans were successively erected on framing built on a large

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pontoon measuring 112 feet by 61 feet, which was moored in the river below the new bridge. When the erection of each set of three ribs was complete, as much as possible of the bracings between the ribs being bolted into position on the pontoon, the pontoon was hauled by tugs into the span to be filled at high water, the framing carrying the ribs having been set so that, in floating them into place, their ends cleared the hinged joints already set in place (Fig. 21, Plate 6). Strong timber stops were fixed between the skewbacks on the piers, against which the ends of the ribs bore as the pontoon moved into position, and when they were immediately over the skewbacks similar timbers were run out on the other side of the three ribs, which were thus held in position until the falling tide lowered them on to the skewbacks. The arrangement of the skewbacks and stops is shown in Figs. 21 and 22, Plate 3. When the three central ribs of each span were in position, the remaining ribs were successively erected on timber beams secured to the bottom flanges of the ribs previously erected.

The bridge was opened for public traffic on the 26th May, 1906, when for the first time a bridge over the Thames was crossed by tramway-cars. It was not, however, until the 5th August that electric cars passed over the bridge.

The total cost of the bridge, including the temporary bridge, and property, was about £480,000, the works of the first contract costing altogether £168,000, and of the second contract about £140,000.

The construction of the bridge was commenced under the supervision of Sir Alexander R. Binnie, Past-President Inst. C.E., then Chief Engineer of the London County Council, who was succeeded in 1902 by Mr. Maurice Fitzmaurice, C.M.G., M. Inst. C.E. Mr. E. Bazalgette, M. Inst. C.E., was Bridges Engineer of the London County Council until 1902, when he resigned and the Author took his place. Under them Mr. H. Becher, M. Inst. C.E., was Resident Engineer on the works during the later stages of the erection of the bridge. Mr. W. Muirhead, M. Inst. C.E., was Engineer for Messrs. Pethick Brothers, and Mr. W. Traill filled the same position for Mr. C. Wall. Mr. A. Ellson, Assoc. M. Inst. C.E., supervised the steelwork construction for the Author.

The Paper is accompanied by twenty sheets of drawings, from which Plates 4, 5, and 6 have been prepared.

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(*Paper No. 3656.*)

"Pontoon-Bridges for Road-Traffic over Rivers in the Darbhangah District, Bengal."

By EDWARD GOLDING BARTON, M. Inst. C.E.

IN 1898 the Author was asked to prepare drawings and estimates for five pontoon-bridges to carry the road-traffic at Mugerdi ghat over the Bor Gandak river, 465 feet in width; at Singhia ghat over the Bor Gandak and Maghmati rivers, 558 feet in width; at Kallunja ghat over the Baghmati river, 403 feet in width; at Hya ghat over the Baghmati river, 341 feet in width; and at Hya ghat over the Kumla river, 310 feet in width.

These rivers rise in the Nepal Hills and flow southwards through the flat alluvial sandy soils of the plains into the Ganges river. During the monsoons they overflow their banks in many places and flood the surrounding country; their courses are tortuous and constantly changing, and their beds are liable to be scoured out to great depths, or silted up. To build permanent bridges over them would entail large expenditure, not only on account of the great depth of the foundations that would be necessary, but also on account of the training-works that are so often required to keep the channel in its place, and such bridges are therefore in most cases beyond the means of District Boards for road-traffic.

Each of the rivers is navigable for ordinary country boats for 6 or 7 months in the year. During the remaining months the channels in the river-bed are small and shallow, and often fordable. The general section of the rivers shows a depth of 15 to 20 feet, with banks having slopes of about 4 to 1 on one side of the river and 1 to 1 on the other side, the difference being due to the direction of the current of the river at that place. As these rivers flow through sandy soil and silt of great depths, their banks are continually being cut away and falling in, and so altering the course of the river.

It was decided to construct these pontoon-bridges (Figs. 1, Plate 7) with single cylindrical pontoons, 6 feet in diameter by 30 feet in

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length, with conical ends, making the total length of the pontoon 36 feet 8 inches. The pontoons are built of steel plates $\frac{3}{16}$ inch in thickness, with internal stiffeners, and each pontoon is provided with a man-hole; when these are properly closed, the pontoons are quite water-tight and unsinkable (Figs. 2, Plate 7). The chief reasons for adopting this form of pontoon were, first, that in the dry season the pontoons are liable to rest on uneven ground either in the bed of the river or on the slope of its banks, and this form gives the greatest strength to resist the stresses to which they are then subjected; second, that it is water-tight when wholly immersed; and third, that the single pontoon is a cheaper form of construction than double pontoons of smaller size. The pontoons are spaced 31 feet apart, between centres, and each pontoon is subject to a dead weight of 8·98 tons and a live load of 3·66 tons, or a total load of 12·64 tons, so that when two adjacent spans are loaded the pontoon between them is half immersed. The extra weight to be carried by the pontoon on which the lifting-gear is operated—due to the weight of the lifting-gear and of the gangway lifted—is 4·21 tons, so that the maximum weight which this pontoon has to carry is 13·19 tons. When the opening span is raised, the pontoon in this case actually sinks 6 inches to 9 inches over the half-immersion line, and accordingly, in order to increase the stability of this pontoon an extra pontoon, although not absolutely necessary, has been placed alongside it. The pontoons were originally moored to mushroom anchors, three to each pontoon, by means of ½-inch chains, two up-stream 100 feet in length and one down-stream 70 feet in length. The positions of these chains are indicated by dotted lines in Fig. 1. They were fastened to rings at the ends of the pontoon which are attached to an iron rod running through the centre of the pontoon longitudinally. This rod is in two pieces, joined in the centre by a coupling-screw.

It was found, however, that, owing to the great scour and silting up of the rivers during the monsoons, and also to the trees and debris brought down in flood-time, considerable trouble and anxiety for the safety of the bridges was caused by anchors dragging; the pontoons were tilted and pulled down by the weight of the trees and debris on the anchor-chains, and sometimes these chains were broken. During high floods one chain out of six or eight would be bearing the whole strain of three or four pontoons against the strong current. The first alteration made was to fasten the anchor-chains to the gangway instead of to the ends of the pontoons, with the result that no more tilting of the pontoons was experienced. The arrangement finally adopted, however, was to moor the whole

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bridge by means of three $\frac{5}{8}$-inch anchor-chains in place of the $\frac{1}{2}$-inch chains from each pontoon. One chain, 200 feet in length, is fixed to the centre of the bridge and attached to a screw-anchor in mid-stream, and two chains, 300 feet in length, one on each side of the centre, halfway between the centre and the shore-ends, are attached to shore-anchors on the banks, on the up-stream side of the bridge (Figs. 1).

The gangways give a roadway 8 feet in width between the wheel-guards and 11 feet in width between the handrails, thus allowing foot-passengers to pass vehicles on either side. They consist of two rolled-steel girders with cross girders at the ends and in the centre. The floor-timbers rest on the two longitudinal girders and are held in place by the timber wheel-guards, which are fastened to the longitudinal girders. Small spikes are driven in the ends of each floor-timber to prevent the latter from shaking out (Figs. 3, Plate 7). The renewal of any particular floor-timber is therefore a simple matter. The timber wheel-guards are fastened by bolts to the girders. The gangway is designed to carry a live load of 3·66 tons and a bridge load of 4·63 tons, giving a total distributed load of 8·29 tons. The handrail of the gangway consists of tee-bar stanchions which drop into wrought-iron brackets bolted to the webs of the girders, a top-rail of angle-bar, and three galvanized-iron wires. The spaces between the gangways are closed by three chains hooked on (Figs. 2).

At the ends of each girder are bolted brackets, each bracket resting on a steel bar 3 inches in diameter, fixed in a saddle which sits in a cast-iron bracket riveted to the pontoon (Figs. 2, 3 and 4). Any tendency of the saddle to slide up out of the bracket in which it rests is prevented by a stud-bolt with a ring head (shown in Figs. 2). As it is only necessary for one end of the gangway to revolve on the axle-bar the other end is keyed by means of a pin and cotter inserted at *a* (Figs. 4). The brackets originally used were of cast iron, but it was found after opening the bridge for traffic that these were unsuitable, as the jar and vibration of heavy loads passing over the bridge broke them. Wrought-iron brackets were therefore substituted, and these have proved quite satisfactory. On one occasion both end brackets broke at the same time, with the result that the gangway fell in, and to prevent this from happening again short iron chains were fastened to the girder and the pontoon (as shown in Figs. 2). Some of the cast-iron saddles (Figs. 4), also broke, and had to be replaced. As there is considerable strain on these at places where they are keyed, they are now being gradually replaced by wrought-iron

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saddles (Fig. 5, Plate 7), which have the same effect as cast-iron saddles which have been keyed.

The spaces between the gangways where the bridge is level are filled in by timbers (shown in Figs. 3) which rest on the flanges of the end cross girders, but where there are expansion roller-paths, or where the bridge is not level, an iron grating (Fig. 6) is used, hinged at one side and free to move at the other side. The end gangways of the bridges rest on wooden platforms supported on piles.

In order to provide for variation in length of the bridge, due to the rise and fall of the river, or to its resting wholly or partially on the uneven bed of the river, the ends of the gangways in certain places are supported on rollers free to roll on roller-paths mounted on the pontoons; five or more sets of these rollers are provided to each bridge, namely, one on each end, one on each sloping bank and one at the opening span. Each of these roller-paths allows for an alteration in length of about 12 inches (Figs. 2 and 7).

The opening span for navigation is arranged for by raising one end of a gangway, allowing the other end to revolve on its axle-bars. As these bridges are situated at out-of-the-way places, where constant supervision is not available, and each bridge is worked entirely by one khallassi and two coolies, it was essential that the lifting and lowering of the opening span for the navigation-channel should be simple, expeditious, easily worked by two coolies, and of such a nature that there could be no danger of letting the gangway fall when it had been raised. These conditions have been satisfactorily fulfilled by means of 10-ton hoists supplied by Messrs. Herbert Moriss and Bastert, of Empress Works, Loughborough (Figs. 8, Plate 7). Two hoists are employed, one on each side of the gangway. The chain is of "treble best" iron, working in a pocketed wheel having chilled driving-edges. The worm-wheel, which gears with a double-thread worm, is cast in one piece with the pocket-wheel; its teeth are cut from the solid metal, which is afterwards hardened. Each hoist is provided with an automatic brake which sustains the load at any point. The time occupied in raising the span is 15 minutes, and in lowering, 6 minutes. The handles of the winches are removed when not in use.

Owing to the cutting and silting that takes place in these rivers every year, it is necessary annually, after the monsoons are over, to adjust the slope of the banks where the pontoons rest on them so that the slope of the gangways may be distributed over three or four spans as may be required, in order that no gangway may have a greater slope than about 1 in 10. In order to do this the bank has

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sometimes to be cut away, or a wooden trestle may be put under a pontoon to raise it, or sometimes both operations may be necessary. On the steep slopes of the bridge the floor is covered with earth to a thickness of 2 or 3 inches, so that bullock-carts can easily get up and down. Whenever these works require much labour or expense, the alternative plan of taking off the handrail of the third or fourth span on one side and making a temporary approach-road to it down the slope of the bank is adopted. This will last during 7 or 8 months in the year.

The erection of these bridges involved no riveting at the site, and should it ever be required to reduce or increase the length of a bridge or to transfer it to some other place, this can be done easily and quickly.

Most of the pontoons are accessible for painting in the dry season; access to the undersides of those which are always afloat is obtained by raising the pontoon till it is just clear of the water by means of four levers, one on each side of the pontoon and on each side of the gangway. Each lever has about 2½ tons to lift. When the water is too deep for this method to be adopted, two barges are floated, one under each gangway on either side of the pontoon to be lifted, and the ends of the girders next to the pontoon to be lifted are jacked up till they come out of the saddles on which they rest. The pontoon, being then free, is allowed to turn bottom upwards, which it does owing to the weight of the cast-iron brackets riveted on top of it. Neither of these operations necessitates stoppage of the traffic.

The actual cost of the bridges described, including the alterations and additions referred to, amounted to £6 10*s*. per lineal foot, but with the information now obtained they should not cost more than £5 10*s*. per lineal foot in the same locality. The bridges were erected and opened for traffic during 1900–1902.

The Paper is accompanied by four sheets of drawings, from which Plate 7 has been prepared.

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(Paper No. 3634.)

"Sketch-Mapping, with Special Reference to Southern Nigeria."

By Lindow Hereward Leofric Huddart, M.A., Assoc. M. Inst. C.E.

When a large area in an uncivilized and little-known district has to be examined with a view to frame a report upon its mineral and other resources, probably the first requisite is a map which shall give a fairly accurate representation of its topographical features. It is usually out of the question, with the time and money available, to carry out a systematic survey of the ground, such as a triangulation or theodolite traverse survey; if the district is proved to be valuable or to possess prospective worth this will probably be undertaken later, but it is with the preliminary mapping that the Author proposes to deal in this Paper.

The mapping will probably have to be done by, say, two white men, with totally unskilled assistance; moreover, this work will be only one of the many duties of the engineers, and will have to be done without much delay at halts, or an absorption of time disproportionate to the importance of their other work. Under such conditions the Author has felt the want of a collection, within small compass, of simple methods of observation, astronomical and otherwise, which are required in the field. The necessary books are bulky and cannot conveniently be taken about when travelling light. He has therefore endeavoured to set forth, in this Paper, in a convenient form for use in the field, some methods that have been found suitable under unfavourable conditions of ground and transport, and which have been used by him under all sorts of conditions in a tropical country.

A preliminary sketch-map should show, with reasonable accuracy, the courses of the rivers in order to enable a proper value to be attached to the results obtained from an examination of their gravels and beds, should these indicate the presence of valuable minerals in the drainage-area. It should also show the positions

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of villages and the approximate distances between them along the connecting paths. In the case of navigable rivers the minimum depth of water available in the dry and wet seasons should be noted.

Nature of the Country.—In considering the methods to be employed, it will be assumed that the district to be mapped contains no roads in the ordinary acceptation of the term, but merely paths and trails which may need to be cleared in order to permit of the easy passage of carriers with loads on their heads; and about which little, if any, plotted information is available. The ground to be worked over may be of one or other of the following descriptions, or of a combination of them:—

(*a*) Primeval and secondary forest with dense undergrowth.

(*b*) "Scrub" or orchard country.

(*c*) Open country; (1) flat, or (2) hilly.

(*d*) Flat cultivated country intersected by navigable streams.

The case (*c*) will not be considered, as it presents a simple proposition requiring no comment, in which rapid work may be done by the usual methods. Country which is covered with scrub (*b*) will usually afford lines of sight up to about 500 feet in length, and, where the grass is not too high, occasional distant views, which at least give some idea of the ground that is being approached; and methods similar to those used for forest (*a*) are applicable, the conditions, however, being more favourable; the paths are usually better, and it may be easy to use a measuring-wheel. Navigable waterways (*d*) can be sketched by obvious methods while travelling by canoe, boat or launch, due allowance being made for velocity and change of tide or current, quantities which are not always easy to determine. In general, the distances are likely to be too great when travelling downstream. If time permits, distances may be computed from sextant-angles upon signals attached to a bar, at a known distance apart; the bar may be made of bamboo and kept in another boat or canoe following, with instructions to exhibit it at the bends in the course of the stream, the observation being made from the leading boat at the end of the reach.

When the area to be examined is covered with dense tropical forest consisting of trees which may exceed 150 feet in height and dense secondary undergrowth (*a*), the problem is difficult. The following case is taken as typical:—Few paths are available, and these are about 2 feet in width, whilst penetration laterally from them involves clearing. The ground is hilly in places, and gradients of 30° to 40° from the horizontal are often encountered on the trails; in general configuration the country is undulating,

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but in detail it is made up of steep valleys drained by small streams leading to a series of main rivers which have to cope with a rainfall of 100 to 180 inches per annum. The usual length of a line of sight does not exceed 50 feet, and is often much less. The object is to obtain, with the least expenditure of time and money, a sketch-map showing the main topographical features with sufficient accuracy to meet the requirements of the case.

General Methods.—The methods employed will depend upon individual choice and the nature of the country. They may be roughly classified according to the observations involved, thus :—

(1) Compass bearings and distances, i.e. compass traverse.

(2) Azimuth and latitude.

(3) A combination of (1) and (2).

The methods are simple in themselves and require no comment where the conditions are favourable, but in the forest country that has been described, when the length of sight is short, the difficulty of obtaining sufficiently long bearings of direction is considerable. The rate of progress, ruled as it is by other considerations than that of mapping, is too fast to permit of direct measurement by steel bands or tapes, and distances must therefore be determined by other means.

Where the path or trail is sufficiently unobstructed by fallen trees or boulders, a measuring-wheel may be used. A serviceable instrument has a wooden wheel of known convenient circumference, say 10 feet, with a brass tyre. Brass is better than iron for this purpose when using the compass. The wheel is guided and pushed by means of a short handle attached to a brass fork, on which is mounted the brass axle or hub. Upon this fork near the axle is fixed a revolution-counter, indicating the distances either in revolutions of the wheel, or in any convenient unit of length. The counter is set at the commencement of the day's march, and is read whenever a bearing is taken. The difference from the last reading is the distance covered. It is convenient to take the bearings as back-sights. The bearings cannot be taken every few yards, and distant points are hidden by the trees and windings of the path. Approximate results, which alone are possible under the circumstances, can be obtained by taking bearings at equal intervals of time back to a native, who is instructed to give forth his forest-cries as soon as he hears a whistle. Any conspicuous object that can be seen from several points will be used as an objective for a bearing. Frequent bearings of the path, whenever a clear 50 yards of it can be seen, afford a good means of determining the general direction ; for, although native paths change their direction

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frequently, nevertheless they take a fairly direct course between two villages. As the march proceeds, the route, with particulars of all hills and rivers that are encountered, is sketched in without interfering with the main duty of panning the streams and examining the rocks, the only methods allowable under the conditions being such as do not in any way interrupt, but rather supplement, the other work.

In rough ground, where a wheel cannot be used, distance must be determined by rate of marching (excluding for the present camp-to-camp distances obtained from difference of latitude). This is very variable. Carriers march at different rates depending upon their loads; the nature of the ground, whether steep or flat, sandy or stony; the time since the last halt and meal; food supply, etc.; so that the rate has to be determined for each special case. It is much easier to determine the rate when a through-march is being made, with only the halts necessary for rest and food, than when stops for panning, detailed examination of rocks and cutting paths laterally from the trail have to be made frequently.

The following are, roughly, the speeds at which carriers march in Southern Nigeria[1]:—

(*a*) 88 yards per minute (about 3 miles per hour) for 2 hours after starting.

(*b*) 75 yards per minute (about 2½ miles per hour) for the remainder of the morning.

(*c*) 65 yards per minute (about 2·2 miles per hour) during the afternoon, and ascending hills.

(*d*) 45 yards per minute (about 1½ mile per hour) in descending hills.

The rates, however, will vary greatly and are only illustrative, as they must be determined for each particular case.

A method of determining distance based upon the velocity of sound has been found by the Author to allow any particular area covered with dense forest to be sketched in rapidly, with sufficient accuracy to give some idea of the ground. One observer remains at a station, A, provided with a revolver, some cartridges, and a watch having a seconds hand, preferably a stop-watch indicating fifths of a second. A second observer, provided with a revolver, some ammunition and a compass, goes to the various points, B, which it is desired to locate with reference to A, and which should not be at greater distances than about 5,000 feet from A. A series of signals having

[1] *Vide* "Bush Sketching," a pamphlet by Captain W. H. Beverley, Staff Intelligence Officer, Calabar.

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been pre-arranged, B signals A that he is ready: A thereupon fires a single shot, noting the time; B replies by firing a shot the instant he hears that of A, upon hearing which A records the time in seconds. This is repeated three, five, or any convenient number of times, and when A is satisfied he signals to B to that effect, whereupon the latter moves on to the next point. The observer at B takes bearings with his compass at every opportunity of the direction from which the sound of A's shots appears to come. In practice it is found that two observers, trained in accurate observation, have fairly regular personal factors, which are made up of—

(1) The interval which the observer at A allows to elapse between his observation of the time and pulling the trigger.

(2) The interval of time lost by the observer at B in replying to the sound of A's shot; this is considerable, as an appreciable time is required for the ear to gather the sound and for the nerve to transmit from the brain the impulse to pull the trigger.

(3) The interval which A unconsciously allows to pass before recording the time of his hearing the replying shot from B.

These factors, of which (2) is the largest, are much more constant than might be supposed; they seem, moreover, to be fairly independent of the distance, so that

if D denotes the distance in feet;

T the time-interval recorded by observer A, which is the time (subject to correction) taken by the sound to travel to B and back;

V the velocity of sound in air,

and B a constant expressing the sum of (1), (2) and (3);

then $$D = \frac{T - B}{2} . V.$$

In the instances in which the Author has used this method for sketch-surveying in forest it has been found that B=0·8 second to 0·7 second, according to the ammunition used. Of this about 0·6 second is lost under heading (2). V is taken as 1,142 feet per second. The bearings can be taken within 5° or 6° by an observer accustomed to note the direction of sounds by compass. If the distances between stations which have been fixed by bearings and distances radiating from a central point (e.g. the camp) be also determined by sound-signals, a sort of rough triangulation is set up and the points can be adjusted into their mean positions. When there has been an opportunity of fixing these points afterwards by traverses, it has been found that they are well within the limit of

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accuracy of a good sketch-survey, the distances being far more accurate than pacing over rough ground would have afforded, whilst pacing in these instances was out of the question, scrambling over roots and logs and pushing through undergrowth being the usual conditions under which the work was done. As the value of T used is that taken by the sound to travel forward and back over the distance, the effect of wind and air-current is largely eliminated. In the following Table are given some examples, taken from the field-book, of points fixed by this method and afterwards checked by traverses. The area to which they refer was covered with primary forest of considerable denseness.

1	2	3	4	5	6	7	8	9
Description of Line.	Distance		Error.	Bearings		Variation between Col. 5 and Col. 6.	Mean of Observed Times.	$B = t_1 - t$ where $t = \frac{D}{571}$. Value of B.
	As found by Traverses.	From Sound-Signals using $B = 0{\cdot}80$.		As found by Traverses.	From Sound.			
	D Feet.	Feet.	Per Cent.	Degrees.	Degrees.	Degrees.	Seconds.	
Blazed tree to 0	990	914	−1·62	S. 3 E.	S. 8 E.	5	2·44	0·71
3 W. to 3 E.	1,080	990	−8·3	N. 67½ E.	N. 63½ E.	4	2·53	0·64
3 W. to 3 S.	1,190	1,170	−1·68	N. 44⅜ E.	N. 40 E.	4⅜	2·85	0·77
Peg E. to 1,500 W.	3,020	3,080	+1·99	S. 84½ W.	Due W.	5½	6·20	0·91
1,500 N. to 7 S.	2,395	2,445	+2·08	S. 1 E.	S. 3 W.	4	5·08	0·89
							5)	3·92
							Mean B	0·784

The mean error in distance is 3·1 per cent., including the line "3 W. to 3 E."; if this is excluded the error is about 1½ per cent. The mean of the variations in compass bearings is about 4½°.

From the foregoing, an idea of the range within which the distance can be estimated may be obtained. The high result shown in the line "3 W. to 3 E.," giving an error of 8·3 per cent., is probably due to bad timing and is hardly typical; it has been included as an example of an unfavourable case. Estimation of the distance within 2 or 3 per cent. is as much as can reasonably be expected of the method. It will be seen that there is fair agreement between the actual and observed bearings (columns 5, 6, and 7). Each observa-

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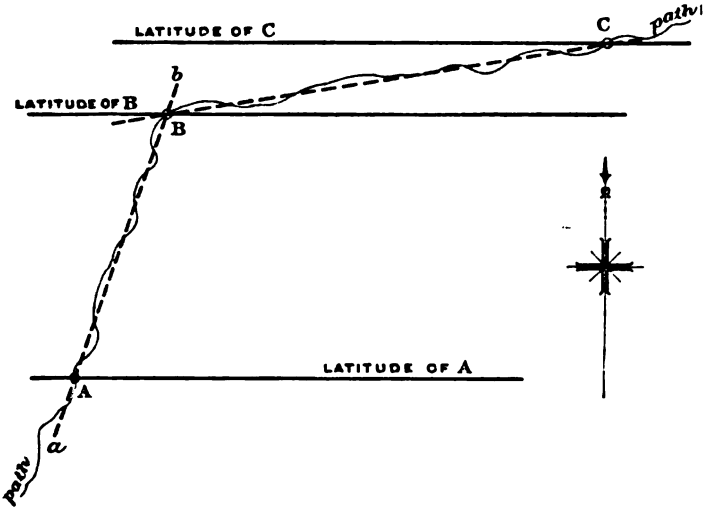
tion, after the observers are at their posts, occupies about 7 minutes, including the necessary signals to "stand by."

Differences of longitude cannot be computed with any approach to accuracy, as a watch cannot be relied upon to maintain an even rate when travelling on land under such adverse and rough conditions. If, however, a through-journey from a point A to B and back to A can be made, the watch rate can be corrected on returning to A and a rough result obtained, if the journey has been in an easterly and westerly direction; but unfortunately there is not often an opportunity to make marches of this description during a preliminary examination. Good results may be obtained by arranging to traverse

Fig. 1.



the concession or area in a roughly north and south direction, when latitudes and azimuths may be used. The azimuths will have to be determined from the bearings of the direction of the path when travelling between the two points, and the through-bearing of the one point, A, to the other, B, computed from these, *Fig. 1.*

The value of the results depends largely upon the judgment and experience of the observer. Some help may often be obtained from natives, especially hunters, who have a good idea of the direction in which a place lies and will point with considerable accuracy. This may appear trivial, but it has been found to be of considerable service. Supposing the last camp at which an astronomical observation was possible to be at A, and the route to be towards some

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place B. On the march the route will be roughly sketched in. When B is reached its latitude is determined, and its position on its parallel is fixed by the bearing of the dotted line *ab* computed from the sketch made *en route*. The sketch is then fitted in between the two points A and B. The distance between them may be more than one day's march. Cloudy and rainy weather may make stars invisible during the halt, and the forest may be too dense to permit of a sight being taken even when the weather is clear. It is often possible to observe from a sand-bank in the middle of a river when the camp is near one of any size. Latitudes will in general be more accurate than azimuths. After leaving B and proceeding to a camp at C the conditions are less favourable, since a slight difference in the bearing of BC will make a considerable difference in the position of C upon its parallel of latitude. The distance, as computed from time and rate of marching, should be judiciously combined with the azimuth; the two will not, unfortunately, give the same position upon the parallel of latitude, but the point may be plotted within these limits, giving greater weight to distance when the rate has been uniform, the path fairly flat, and the halts less frequent; and to azimuth when the conditions are the reverse of these. The latitude is best obtained from observations on stars, especially in the tropics, as it is difficult to secure adequate protection of the head from the sun's rays while making solar observations, especially with a sextant; in addition there is the simplicity of the computations and the increased accuracy in observing the altitude of a point of light like a star. Whenever possible, both north and south stars will naturally be observed, the mean of the latitudes so obtained being taken; but in forest country it may often be necessary to make the best of whatever northerly or southerly stars happen to be visible through a gap in the branches overhead—if indeed they can be identified. In such a case it is advisable to observe two different stars, even although they may be both on the same side of the Prime Vertical. Methods of observation that are least fatiguing and require the minimum of night-work, and which have been found satisfactory in practice, will be described. Extreme precision cannot be expected and is not aimed at; nor can time be spared for long halts to wait for a fine night or for clearing.

Latitude by Meridian Altitude.—The apparent times of meridian passage of the principal stars are given in tabular form in various publications,[1] and hence the mean time at any place can be computed

[1] "Practice of Navigation," by Henry Raper, R.N.; "Hints to Travellers," published by the Royal Geographical Society, etc.

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by adding or subtracting, as explained in the Nautical Almanac (p. 1), the equation of time reduced for the date[1] and longitude. If no Table is available the astronomical mean time (M.T.) of passage across the meridian is determined in the following manner:—

Let ρ denote the right ascension of a star, to be increased if necessary by 24 hours if τ is greater than ρ;

τ the sidereal time at mean noon for the date (Nautical Almanac, p. 2);

R the retardation upon approximate M.T. of transit, taken from Tables;

A the acceleration for the longitude, taken from Tables,

then the approximate M.T. of transit

$$= \rho - \tau,$$

or (if τ is greater than ρ)

$$= (\rho + 24 \text{ hours}) - \tau;$$

and accurately, allowing for the retardation and acceleration upon this approximate M.T. of transit,

$$\text{M.T. of transit} = (\rho - \tau) - \text{R} - \text{A} \text{ in west longitude,}$$
$$\text{or} = (\rho - \tau) - \text{R} + \text{A} \text{ in east longitude.}$$

It is often sufficient to know the time of transit to the nearest minute. It is also often convenient to know the altitude of the star about to be observed; this is especially useful when it is unfamiliar, the sky cloudy, and only a small part of the adjacent constellation is visible, as, for example, when observing in a forest through gaps between the trees. The altitude need only be computed to the nearest minute of arc, since the observation is for latitude. With the telescope clamped to the altitude on the vertical circle, allowing for refraction, and the horizontal plate in the meridian, allowing for variation of the compass, and knowing the approximate time of meridian passage, the location of the star is facilitated.

Let λ denote the latitude;

α the true meridianal altitude; i.e., the observed altitude corrected for refraction, and, in the case of the sun, for parallax, and for semi-diameter if only one limb has been observed;

[1] The term "date" is used throughout to denote the day, hour, minute and second of an observation, e.g., 3rd June: 8h. 8m. 15s. P.M. has as "date" June, 3 days, 8 hrs. 08m. 15s.

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δ the declination (Nautical Almanac, p. 2) south or north corrected for the date in the case of the sun or a planet;

z the meridianal Zenith distance $= 90 - a$, which is called "North" if the observer is north of the star, and "South" if he is south of it

Then (1) $a = 90 - \lambda + \delta$ when λ and δ are of the same name. If the sum exceeds 90° ($90 - \lambda + \delta$ being called the sum), $a = 180° -$ sum;

(2) $a = 90° - \lambda - \delta$ when λ and δ are of opposite names, and the observed altitude $a_1 = a +$ refraction.

Having selected a star that has a convenient time and position, the theodolite is set up, and observations of the altitudes, "face right" and "face left," are commenced some five or ten minutes before the computed time of transit. The star will move almost horizontally across the object-glass. Observations are continued until the mean altitude is perceptibly diminishing. The barometer and thermometer are read to enable the refraction to be corrected for temperature and pressure, and, having chosen the highest pairs of altitudes, the mean of these is taken and the latitude is computed in the following manner:—

When z and δ are of the same name

$$\lambda = z + \delta$$

and is of the same name; and when z and δ are of opposite names

$$\lambda = (z - \delta) \text{ or } (\delta - z),$$

and takes the name of the greater.

When corrections have to be applied to the declination and "equation of time," it is necessary first to find the Greenwich date as follows. It is assumed that the local mean time is known from observations for time, and that the longitude is known roughly. Then

(1) In east longitude the Greenwich date = astronomical local mean time − longitude in time.

	D.	H.	M.
Example:—Astronomical date, June	1	1	20
Longitude[1] 120° E. . . . . −		8	0
Greenwich date, May . .	31	17	20

[1] $\frac{\text{Longitude in degrees}}{15}$ = longitude in time.

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(2) In west longitude the Greenwich date = astronomical local mean date + longitude in time.

	D.	H.	M.
Example:—Astronomical date, June	3	17	18
Longitude 130° W. . . . . +		8	40
Greenwich date, June . .	4	1	58

In astronomical time the day begins at mean noon, and the hours are counted onwards from 0 to 24, which is noon of the following day; hence midnight is called 12 hours, and all A.M. civil times must be increased by 12 hours, and the day of the month reduced by one. Therefore, having found the Greenwich date, the declination of the day at noon (Nautical Almanac, p. 11) is noted, and the hourly variation, multiplied by the interval in hours and decimals of an hour from noon of the day of observation, is applied, with its proper sign, which depends upon whether δ is decreasing or increasing.

In stellar observations these corrections are not necessary. The equation of time is corrected similarly. The change in 24 hours at the date of observation is found from the Nautical Almanac; then if d denotes the variation (+ or −) in 24 hours of the equation of time, and m the fraction, Greenwich mean date at place of observation divided by 24 hours, the correction is $\pm m d$.

When observing the sun by means of a transit theodolite, the correction of altitude for semi-diameter may be eliminated by taking the upper and lower limbs "face right" and "face left" alternately, and similarly when observing for azimuth by taking the right and left limbs.

Latitude may also be obtained by circum-meridian altitudes, or double altitudes, which require the apparent time to be accurately known. These methods will not be described, as the meridian altitude has been found convenient for the class of work here dealt with.

An excellent method of determining the latitude when the pole-star is visible is given in the Nautical Almanac. The true altitude of the pole-star is obtained at the sidereal time S. Since the watches show, in general, mean time, this must be converted into sidereal time; then if

S_{red} denote the reduced sidereal time,
S_n the sidereal time of mean noon,
a_l the acceleration on the longitude,
a_t the acceleration on the mean time,
and T the mean time,

$$S_{red} = S_n \pm a_l$$

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(in west longitude a_l is positive, and in east longitude negative), and the sidereal time required is

$$S = S_{red} + T + a_l.$$

Then the latitude[1]

$$= a - p \cos h + \tfrac{1}{2} \sin 1'' (p \sin h)^2 \tan a,$$

where a denotes the true altitude of the star, p the apparent polar distance, and $h = S - a$, the hour-angle of the star, S being the sidereal time of observation and the apparent right ascension of the star, found from the Nautical Almanac. The Nautical Almanac gives in tabular form the value of the expressions

$$- p \cos h,$$

or the first correction, and

$$\tfrac{1}{2} \sin 1'' (p \sin h)^2 \tan a,$$

or the second correction, and a third correction depending upon the difference between the true and assumed values of p and a.

Apart from attempts which may be made to estimate differences of longitudes when a return-journey east and west is made, it is necessary to know the local mean time for correcting the necessary elements and for other purposes. Time may be computed from the sun, planets, or stars, and the observations should be made when the object is roughly east or west, so that the change of altitude in a given time is large; the reverse is the proper condition when it is the latitude that is required.

Time by Altitude of Sun or Star.—It is necessary first to find the astronomical date; if the watches have stopped, the time may be obtained in the tropics—roughly, indeed, but near enough to correct in the first approximation the elements of declination, etc.—by the time of sunset or sunrise; in this case a correction must be applied to the elements δ and equation of time.

Having obtained the mean of a set of altitudes, and the mean of the times by watch corresponding to the altitudes, the latitude being known, the hour-angle is computed in the following manner:—

Let λ denote the latitude,

a the corrected altitude,

δ the corrected declination,

ϕ the polar distance $= (90 - \delta)$, when λ and δ are of the same name, or $(90 + \delta)$, when λ and δ are of opposite names,

Σ the sum $(\lambda + a + \phi)$

and θ° the hour-angle in degrees, minutes and seconds of arc.

[1] Nautical Almanac, 1905, p. 9.

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Then $$\sin^2 \frac{\theta^\circ}{2} = \sec \lambda \operatorname{cosec} \phi \cos \tfrac{1}{2} \Sigma \sin \left(\frac{\Sigma}{2} - a \right);$$

or, using logarithms,

$$\mathrm{L} \sin^2 \frac{\theta^\circ}{2} = \mathrm{L} \sec \lambda + \mathrm{L} \operatorname{cosec} \phi + \mathrm{L} \cos \tfrac{1}{2} \Sigma + \mathrm{L} \sin \left(\frac{\Sigma}{2} - a \right) = \mathrm{B} \quad . \quad (1)$$

If no "sine square" (Haversine) Table is available to give tabulated values of $\mathrm{L} \sin^2 \frac{\theta^\circ}{2}$, the identity

$$\mathrm{L} \sin^2 \frac{\theta^\circ}{2} = 2 \, \mathrm{L} \sin \frac{\theta^\circ}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

enables the hour-angle θ to be found from Tables of logarithmic sines. From (1) and (2)

$$2 \, \mathrm{L} \sin \frac{\theta^\circ}{2} = \mathrm{B},$$

whence $$\frac{\theta^\circ}{2} = \mathrm{L} \sin^{-1} \frac{\mathrm{B}}{2},$$

and $$\theta^\circ = 2 \, \mathrm{L} \sin^{-1} \frac{\mathrm{B}}{2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

which is easily applied.

Example :—Let $\mathrm{B} = 19 \cdot 068450$, adding the index 10,

then $$\frac{\mathrm{B}}{2} = 9 \cdot 534225$$

and $$\mathrm{L} \sin^{-1} \frac{\mathrm{B}}{2} = 20^\circ \, 00' \, 30'';$$

therefore $$\theta^\circ = 40^\circ \, 01' \, 00'';$$

thus the required hour-angle is 2h. 40m. 4s. This is also useful in taking an azimuth from an altitude of the sun or a star.

Star Observation.—To find the mean time at the place of observation, the right ascension of a star and the sidereal time at mean noon are taken from the Nautical Almanac (p. 2);

then if θ denote the hour-angle in time,[1]

ρ the star's right ascension,

S_t the right ascension of the meridian or local sidereal time,

---

[1] The hour-angle is converted into time thus :—

an hour-angle of $360^\circ = 24$ hours;

therefore $$\theta^\circ = \theta \times \frac{24}{360};$$

whence $$\theta = \frac{\theta^\circ}{15}.$$

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S_n the sidereal time at mean noon (Nautical Almanac, p. 2)
T_1 the approximate mean time,
T the mean time at the place of observation,
r the retardation on T (approx.),
and f the acceleration on T (approx.),

$$S_l = \rho + \theta \text{ for a westerly star.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and $S_l = \rho$ (+ 24 hours if necessary) $- \theta$ for an easterly star . (5)

then[1] $$T_1 = S_l - S_n$$

and $$T = T_1 - r \pm f.$$

In West longitude f is negative; in East longitude it is positive.

If T is less than 12 hours the result is mean time; if greater than 12 hours the time is reckoned on the preceding day. For apparent time it is necessary to apply to T the corrected equation of time as directed in the Nautical Almanac (p. 2).

Sun Observation.—In observations on the sun, the hour-angle θ gives the apparent time when the sun is west of the meridian, but when the sun is east of the meridian—

24 hours $- \theta$ = apparent time on the preceding day,
and mean time = apparent time $\pm$ reduced equation of time (Nautical Almanac, p. 1).

The mean time of the observation, and also the time by the watches being known, the error of the latter is easily found. If the watches were to show Greenwich time, the longitude of the place would be found; if the watches show the time of some other meridian, such as a base camp, the difference of longitude is obtained. Due allowance must be made for rate, which can be determined by finding the error of the watches again in the same meridian after an interval of a few days; the more constant the rate, the greater the reliance that can be put on them.

Variation of the Compass.—It is necessary to know the variation from true North of the magnetic needle so that all work may be reduced at once to the meridian; this is shown on charts of the coast, and these afford a good guide as to what to expect in the interior. In practice the methods depending upon (1) amplitudes of the sun rising and setting, and (2) azimuths from altitudes of the sun or stars, have been found most useful. The former is ordinarily employed by

[1] If S_l is less than S_n, the former must be increased by 24 hours, so that in that case

$$T_1 = (S_l + 24 \text{ hours}) - S_n.$$

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sailors, using the sea horizon, and gives with rapidity on shore results which are near enough for a pocket or prismatic compass, and affords a good check upon the second or more precise method. Instead of the sea horizon the theodolite is levelled and the telescope is clamped in a horizontal plane; the sun's centre is then observed, and its magnetic bearing is shown by the trough compass. The angle from the East, if the sun is rising, and from the West if it is setting (e.g. W. 15° 30′ N.) is the amplitude, called "magnetic" if it is the compass reading. This method is less accurate on shore than with the sea horizon, and the best has often to be made of the sun dipping behind distant trees, with the telescope raised several minutes of arc out of the level; but when on rising ground a level sight can be obtained. The method is susceptible of greater precision in low latitudes. The true amplitude can be found from Tables [1] and by computation. The amplitude is named similarly to the declination, viz. North or South. The variation is West when the magnetic bearing is to the right of the true bearing, and East when to the left, the observer being in the centre of the compass. The direction of the variation can be found easily in the following manner (using continuous bearings, i.e. 0° to 360°).

Let t denote the true continuous bearing;
m the magnetic continuous bearing;
v the variation.

Then, using v algebraically as regards sign,

$$t = m + v \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If the variation is West v is negative; and if East, positive.

Example.—Supposing the true bearing of a point to be 206° 31′ and the magnetic bearing 211° 40′,

$$206° 31′ = 211° 40′ + v,$$
$$v = 206° 31′ - 211° 40′,$$
$$= - 5° 09′,$$

or 5° 09′ West. This method appears to be more convenient than those usually given.

The computation of the amplitude is simple;

if λ denote the latitude,
and δ the corrected declination,

then, taking logarithms,

$$\text{L sin amplitude} = \text{L sec } \lambda + \text{L sin } \delta.$$

[1] *Vide* "The Practice of Navigation and Nautical Astronomy." By H. Raper (Tables 59 and 59*a*).

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For example, if $\lambda = 6° 40' \text{ N.}$, $\delta = \text{S. } 16° 35'$ corrected, and the magnetic amplitude = E. 1° 52′ N.

$$\begin{aligned} \text{L sec } \lambda &= 10{\cdot}002947 \\ \text{L sin } \delta &= \ 9{\cdot}455469 \\ \hline \text{L sin amplitude} \quad & 9{\cdot}458416, \text{ omitting the 10,} \end{aligned}$$

Therefore the true amplitude = E. 16° 42′ N., neglecting seconds,
but the magnetic amplitude = E. 1° 52′ N.;
therefore the variation = 14° 50′ W.

The second method is precise, being especially useful for the orientation of a traverse, a triangulation, or a mine-survey. It is based on the following formula:—

Let a denote the corrected altitude,
λ the latitude,
δ the corrected declination,
ϕ the polar distance,
Σ the sum $(a + \lambda + \phi)$,
R the angle $\left(\frac{\Sigma}{2} - \phi\right)$.

Then $$\sin^2 \frac{\text{azimuth}}{2} = \sec a \,.\, \sec \lambda \,.\, \cos \frac{\Sigma}{2} \,.\, \cos \text{R},$$

or, taking logarithms,

$$\text{L sin}^2 \frac{\text{azimuth}}{2} = \text{L sec } a + \text{L sec } \lambda + \text{L cos } \frac{\Sigma}{2} + \text{L cos R}.$$

Example:—In an observation of the sun for azimuth,

$\lambda = 6° 23' 40''$ N.;
$\delta = 49' 04''$ N.;
corrected $a = 45° 58' 39''$;

magnetic bearing of flagstaff, 326° 24′; horizontal plate clamped on flagstaff at 0° 00′ 00″; temperature 95° F.; barometer 29·1 inches; mean horizontal angle of sun from flagstaff, 142° 01′ 30″; $\phi = 89° 10' 56''$.

Then:—

	°	′	″		
λ	6	23	40	L sec	0·002710
a	45	58	39	L sec	0·158053
ϕ	89	10	56		
2)141	33	15			

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		°	′	″		
$\frac{M}{2}$	70	46	37	L cos	9·517521
$\phi - \frac{M}{2}$	18	24	19	L cos	9·977186
				L $\sin^2 \frac{\text{azimuth}}{2}$	19·655470

		°	′	″	
Therefore,	Azimuth[1] of sun is . . . S	84	31	51	E.
	Or his continuous bearing is . .	95	28	09	
		360	00	00	
		455	28	09	
	Angle from flagstaff . . .	142	01	30	
	True continuous bearing of flagstaff	313	26	39	(say).
	Magnetic bearing	326	24	00	
	therefore, the variation is	12	57	21	

Taking degrees only and using formula (6)

$$t = m + v,$$

i.e., $$313° = 326° + v;$$

therefore $$v = -13°,$$

the negative sign showing that the variation is W.

Conclusion.—Sketch-maps, even if somewhat rough, are of considerable service in an unsurveyed country, but they require to be fitted on to a network of surveys of a more accurate character. The cost of such surveys in tropical Africa, especially near the coast where the forest is thick, as in Southern Nigeria, is considerable, and in many instances cannot be financially justified until trade has begun to develop. Triangulation, requiring a number of towers high enough to be seen over the tree-tops, which are often 200 feet above the ground, is exceedingly costly, and therefore traverses must be employed. The cost of the latter is largely increased by the fact that all lines of sight entail extensive clearing. The rivers running down to the lagoons in Lagos, and to the tidal estuaries in Southern Nigeria, are in the dry season very shallow, consisting of meanders among sand-banks between well-defined banks in their lower reaches,

[1] The azimuth is to be reckoned from the S. in N. latitude and from the N. in S. latitude.

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and of rapids over boulders of gneiss and granite, with occasional falls and deep pools, in their upper parts, so that it is easy to walk along their courses. If lines of traverse were run along the beds of the rivers, the work being confined to the dry season, say December to April, the heavy expense of clearing would be avoided, and points could be fixed where the paths cut the rivers, and villages stand on the banks. The country, having a heavy rainfall, is well drained, and the rivers, in at least the majority of cases, run for a considerable portion of their lengths in a direction roughly north and south. The Cross river takes a sharp bend and runs roughly east and west for a considerable portion of its length in Southern Nigeria, and is somewhat exceptional in this respect. By means of these traverses a net-work running inland from the coast would be obtained, and much of the sketch-mapping already done could be adjusted to it, giving a map upon which reliance could be placed. These traverses would fix many points, and combined with latitudes would be most valuable in affording points of departure for any future work that might be undertaken as the several districts developed sufficiently to warrant the necessary expenditure.

In conclusion, the Author hopes that this Paper may be of some use to engineers who may have to examine and report upon, and prepare a sketch-map of, districts such as that described.

The Paper is accompanied by a diagram, from which *Fig. 1* has been prepared.

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(*Paper No. 3679.*)

"Loss of Pressure in Water flowing through Straight and Curved Pipes."

By ARTHUR WILLIAM BRIGHTMORE, D.Sc., M. Inst. C.E.

IN 1902 the Author had the pleasure of inaugurating, at the Royal Indian Engineering College, Coopers Hill, under Sir J. W. Ottley, K.C.I.E., M. Inst. C.E., the President, a hydraulic laboratory for facilitating the proper teaching of hydraulics. As this College has now ceased to exist, it seems fitting that the experimental investigations which the Author proposes to describe in the following Paper should be placed on record, both on account of the interest which attaches to any carefully-conducted experiments of a useful nature, and also in memory of the short-lived laboratory in which they were conducted.

In arranging the laboratory it was decided that all the experiments to be made should be on a practical basis, and that mere models should not be used, but that all the apparatus should be of types in actual every-day use. As it was necessary to be independent of the College water-supply, a cast-iron tank having a capacity of 14,000 gallons was mounted on six braced steel columns, so that its top water-level was 50 feet above the floor of the laboratory; and a cast-iron tank of similar capacity was placed beneath the floor of the laboratory. The water from the latter was lifted into the upper tank by means of pumps of various types, the efficiency of which could be determined experimentally, and was then available for experiments on the efficiency of the different types of turbines installed, or for the verification of the formulas relating to the flow of water through notches, orifices, channels, pipes, etc.

Loss of Head in Straight Pipes.—Keeping in view the idea of having everything on a practical scale, the pipes used in this investigation were 3 inches, 4 inches, and 6 inches in diameter, and each range of pipes was 50 feet in length. The pipes were arranged in parallel rows, one above the other, as shown in *Fig. 1*, and connected at each end to a common stand-pipe. A full-way stop-valve was fixed on each pipe at its connection to the inlet stand-pipe, and the latter was connected by a pipe to the upper tank. From the outlet stand-pipe a return-pipe, 6 inches in

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diameter, led to the lower tank, a valve being provided on it, in a convenient position, for regulating the flow through the pipe under observation. In the centre portion of this return-pipe two lengths of pipe, 3 inches or 4 inches in diameter, could be inserted for experiments on sudden enlargements and contractions. The pipes were cast specially for the experiments, and were all flanged; they did not vary appreciably from their nominal diameters, but in order to ensure the proper mean velocity being obtained at the points at which the pressures were read, a junction-box 6 inches in length, bored out to the exact diameter, was fixed between the ends of each two consecutive pipes, and the connections to the pressure-gauges (which are numbered in *Fig. 1*) were inserted into the centre of these junction-boxes on their horizontal diametrical plane. In the lower tank was placed a copper float guided in the vertical direction and surmounted by a rod which projected through an opening in the laboratory floor and carried a pointer at its upper extremity. The rod worked inside a flanged tube, screwed to the floor of the laboratory and having a vertical slot in it through which the pointer protruded. The edge of the vertical slot was graduated in gallons by pouring known volumes of water into the tank, and each time marking the position of the pointer. Thus the quantity of water delivered into the lower tank in any given time could be read off. The pipes were connected to the pressure-gauges by copper tubes, $\frac{3}{8}$ inch in external diameter, provided with cocks so that the loss of pressure in 10-foot, 20-foot or 30-foot lengths of the pipes could be read off on the gauges, which were fixed on the adjacent wall of the laboratory.

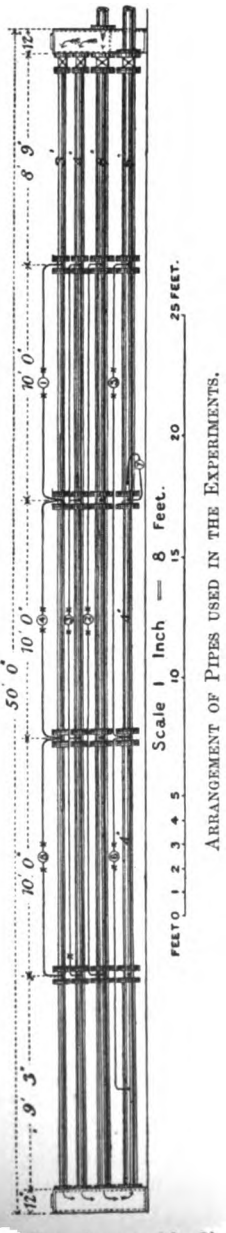

Fig. 1.

Arrangement of Pipes used in the Experiments.

In order to avoid discrepancies due to the proximity of the

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stand-pipes at the ends, the loss of pressure-head in the extreme lengths of the pipes was not measured.

Many experiments have been made at different times on pipes coated with varnish and various other coverings, but it appeared to the Author that a pipe for permanent use should not be credited with a delivery greater than that of a cast-iron pipe rusted but not tubercled, i.e., the condition of a cleaned cast-iron pipe from which the varnish has become detached. It is well known that the condition of the inner surface of a pipe makes a considerable difference in the quantity of water it is capable of discharging under a given head, particularly in the case of small pipes, and that the delivery always falls off as the condition of the inner surface deteriorates. The pipes used in the experiments to be described were therefore not coated, but were allowed to rust, the process being facilitated by the presence of sal-ammoniac dissolved by the water in the tanks from the rust joints; any tubercles which formed in the pipes were, however, scraped off.

The temperature of the water during the experiments did not vary much from 64° F.

The type of pressure-gauge used is illustrated in *Figs. 2*; it is essentially an inverted U-tube provided with cocks, A, at the lower extremities of the legs, which were connected by copper tubes, as already described, to the junction-boxes on the pipes, between which it was desired to measure the loss of pressure. In order readily to get rid of any air in the pipes connecting up the gauges, and to regulate the amount of air in the latter so that the tops of the two water-columns could be easily seen, a three-way cock, B, was provided, which allowed the water to be run out, and also enabled the water-level in the two legs of the tubes to be equalized. To facilitate running the water out of the gauges, two air-cocks, C, were provided at the top, which also served to get rid of any air when oil was used in the upper part of the gauge—oil-cups, provided with cocks, being fixed on the top at the centre, to facilitate the introduction of oil into them when desired. A scale graduated in inches and tenths of an inch, with a rack attached to it, was placed between the two legs of the gauge and was moved by means of a pinion, turned by a milled head, so that the zero of the scale could be placed opposite the water-level in one tube, and the level of the water in the other tube relatively to the latter read off directly. When the loss of head was large enough to be easily read off without magnification, the upper portion of the tube simply contained air, and, since the pressure to which it was subjected was never much more than an additional atmosphere, the weight of the column of air equal in height to the difference of the water-levels in the two legs was

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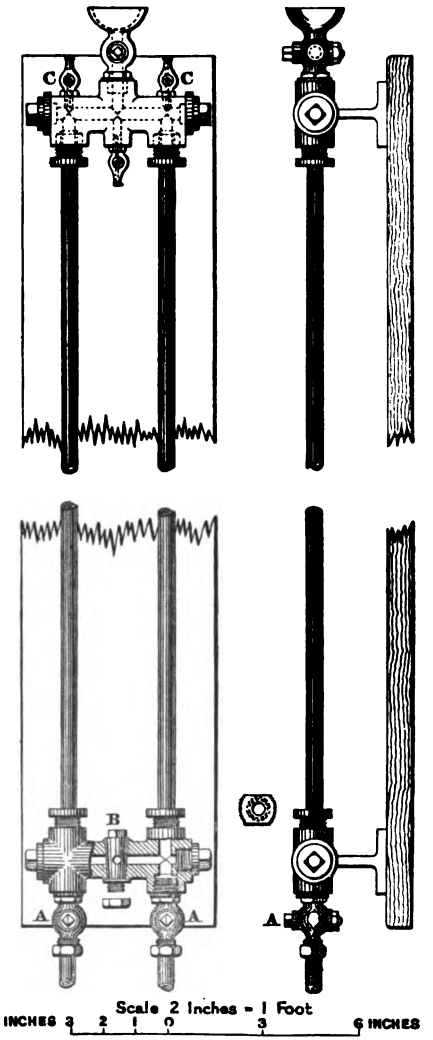
negligible. When the difference of pressure was very small the top of the inverted U was filled with paraffin, the specific gravity of which was found to be 0·812. The difference of pressure was then that due to a head equal to the difference between the heights of the two water-columns, of a liquid having a specific gravity equal to the difference between the specific gravities of water and paraffin; and the magnification of the reading was therefore

$$\frac{1}{1-0\cdot812}=\frac{1}{0\cdot188}=5\cdot32;$$

i.e., the reading was 5·32 times the reading with air.

Figs. 2.



PRESSURE-GAUGE.

The inlet-valve of the particular pipe being experimented upon was fully opened—the inlet-valves of the other pipes being of course closed — and the quantity of water flowing through the pipe was regulated by the valve on the return-pipe. The flow through the pipe in a given time was read off in gallons from the position of the pointer connected to the float in the lower tank, into which the water was discharged; and the loss of pressure in the given length of pipe was read off on the pressure-gauge.

Since the motion of the water in a rough pipe consists of an ever-changing series of eddies, the loss of head between two given sections of a pipe is by no means a constant quantity, but varies

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between certain limits, particularly at high velocities; the average reading on the gauge was recorded in each case. The logarithmic homologues of the loss of head in 20-foot lengths of the 3-inch, 4-inch and 6-inch pipes for velocities varying between 1·1 foot per second and 14·7 feet per second are plotted in *Fig. 3*. The logarithms of the velocities are plotted horizontally and the logarithms of the losses of head in 20-foot lengths are plotted vertically. It will be seen that the plotted results lie in each case on a straight line, except for very low velocities, when the loss of head is proportionately greater than for higher velocities. This increased loss of head at very low velocities is, however, immaterial, as the size of a pipe is ruled by the maximum discharge through it with the available head. The inclination of the straight lines in all three cases is found to be almost exactly 2 : 1, showing that, for the condition of internal surface experimented upon, the velocity varies as the square root of the loss of head.

The equations of the lines in *Fig. 3* are

$$\text{For 3-inch pipe} \quad \text{Log } V = 0{\cdot}124 + \tfrac{1}{2} \text{ Log } h$$
$$V = 1{\cdot}33 \times \sqrt{d\,i}\ \sqrt{240 \div \tfrac{1}{4}}$$
$$= 1{\cdot}33 \times 31{\cdot}0\ \sqrt{d\,i}$$
$$= 41{\cdot}3\ \sqrt{d\,i.}$$
$$\text{For 4-inch pipe} \quad \text{Log } V = 0{\cdot}248 + \tfrac{1}{2} \text{ Log } h$$
$$\text{whence } V = 47{\cdot}5\ \sqrt{d\,i.}$$
$$\text{For 6-inch pipe} \quad \text{Log } V = 0{\cdot}363 + \tfrac{1}{2} \text{ Log } h$$
$$\text{whence } V = 50{\cdot}6\ \sqrt{d\,i.}$$

The coefficients in the Chezy formula for material velocities are thus seen to be constants having the following values for the three cases:—

Diameter of Pipe. Inches.	Coefficient c, in the Formula $v = c\sqrt{d\,i}$.
3	41·3
	47·5
	50·6

v is the velocity in feet per second; d is the diameter of the pipe in feet; and i is loss of head per unit length.

These figures show that the allowance made by Rankine's form of the Darcy formula[1] for the coefficient in the above-mentioned formula, namely—

$$c = \frac{\text{a constant}}{\sqrt{1 + \frac{1}{12d}}}$$

does not give a sufficient reduction for pipes of smaller diameter

[1] W. J. M. Rankine. "Civil Engineering." 12th ed., p. 685.

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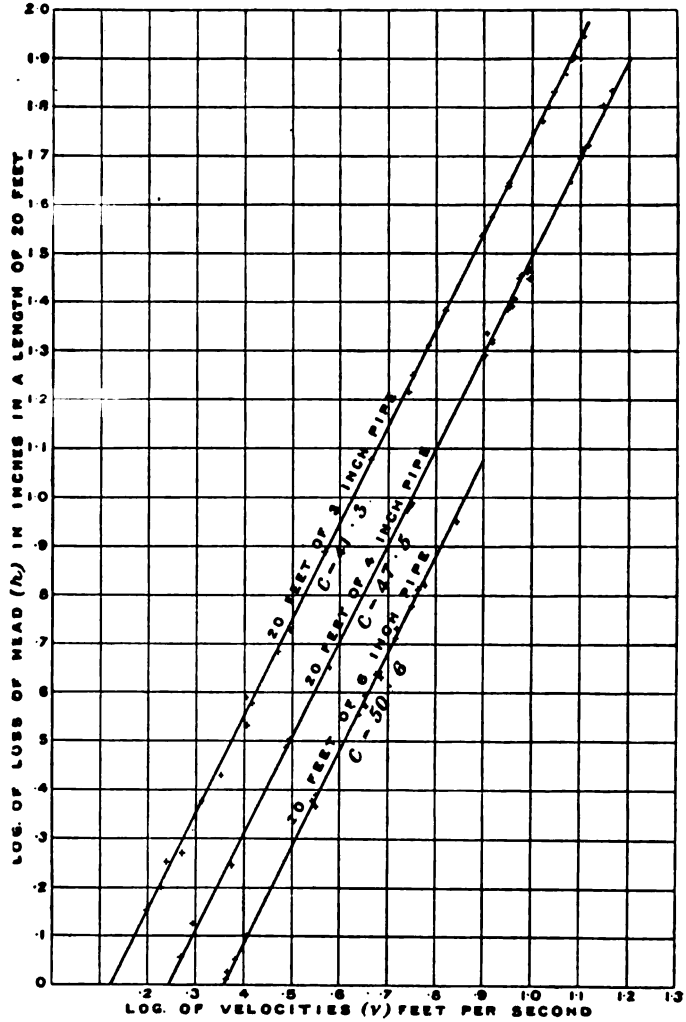
when rusted but not tubercled. The following formula has been devised, which agrees with the foregoing results for small cast-iron pipes in this state and with the values given by Darcy for larger

Fig. 3.



pipes; the latter have been confirmed by numerous experimenters, and are generally accepted as safe values for cleaned cast-iron pipes. The formula for the velocity in cleaned cast-iron pipes which the Author proposes is—

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$$v = \frac{56}{1 + \frac{1}{40\sqrt{d}}} \times \sqrt{d\,i}$$

For large pipes the first factor becomes 56; for 6-inch pipes it is 50·9; for 4-inch pipes 45·7; and for 3-inch pipes 40·0. These values, it will be noticed, agree very well with the experimental results, but the formula favours the smaller pipes, which is a good fault. It is of course recognized that for a smoother internal surface the coefficients would be higher, e.g., in the case of two 3-inch pipes which had to be used fresh from the foundry in the following experiments on enlargements and contractions, the coefficients were specially determined, the values given in Table I being obtained at three different velocities. In Table III, also, are given the values of the coefficients for three different velocities for some 3-inch galvanized pipes used in connection with the investigations relating to bends; in this case, owing to the smoother surface of the pipes, the coefficients are considerably larger and also vary with the velocity.

Loss of Head at Sudden Contractions and Enlargements.—As no reliable experimental data on the subject of loss of head at sudden contractions and enlargements are available, so far as the Author is aware, the following series of observations of such losses at sudden contractions from 6 inches diameter to 4 inches diameter, and from 6 inches diameter to 3 inches diameter, and at corresponding sudden enlargements, may be of interest. As the eddies induced by such sudden changes in the velocity take some time to die out, it is obvious that to measure the total loss due to such changes it is necessary to measure the loss in a length of pipe containing such contractions and enlargements, allowing a sufficient length on the discharge-side for the additional eddies to die out, and for the flow to become normal again. The measurements of loss of pressure were therefore made from a point some feet away on the approach-side to a point about 10 feet away on the discharge-side (gauges Nos. 5 and 6, *Fig. 1*), and then allowance was made for the loss of head at the corresponding velocity in the lengths of pipe included; there had also to be taken into account, in the case of contractions, the decrease of pressure due to the increase in velocity, and in the case of enlargements, the increase of pressure due to the decrease of velocity. In the change from 6 inches to 4 inches diameter the coefficient found from the experiments on similar pipes in the range was used, but in the change from 6 inches to 3 inches diameter, as the 3-inch pipes inserted in the length of 6-inch return-pipe,

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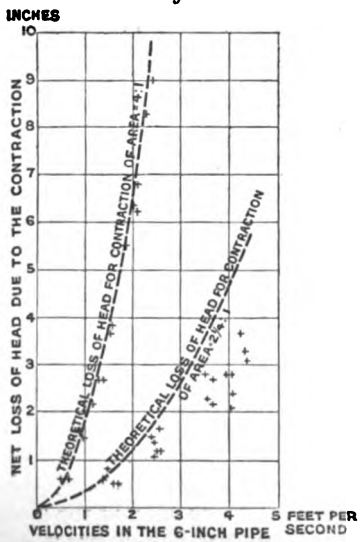
in place of the 4-inch lengths shown in *Fig. 1*, were new from the foundry, the coefficients were specially determined for those two lengths; the values obtained are given in the following Table :—

TABLE I.

New 3-Inch Pipe following Contraction. 6 Inches to 3 Inches.			New 3-Inch Pipe preceding Enlargement. 3 Inches to 6 Inches.		
Velocity.	Loss of Head in 9-Foot Length.	Coefficient.	Velocity.	Loss of Head in 9-Foot Length.	Coefficient.
Feet per Second.	Inches.		Feet per Second.	Inches.	
5·2	4·4	51·2	5·2	4·6	50·0
8·1	10·3	52·1	8·1	11·6	49·7
9·3	13·8	52·0	9·4	15·6	49·3
Average coefficient .		51·8	Average coefficient .		49·7

These averages were used in calculating the loss of head in these pipes; and they prove that the mere rusting of the inside surface of the pipes considerably reduces their discharge under a constant head. The results of these experiments are plotted in *Figs. 4* and *5*. Velocities are plotted horizontally, and the net loss of head vertically, and it will be seen that for a contraction and an enlargement of two and a quarter times, the measured losses, which are indicated in each Figure by crosses, are less than those given by the expression $\frac{(V-v)^2}{2g}$ (where V is the velocity in the smaller and v the velocity in the larger pipe), which are indicated by the dotted curves. It will also be seen that for a contraction and an enlargement of four times, the losses of head actually measured are, in each case, in very close agreement with the theoretical values.

Fig. 4.



NET LOSS OF HEAD AT SUDDEN CONTRACTIONS OF AREA OF $2\frac{1}{4}$: 1 AND 4 : 1.

It is interesting to compare the loss of head in a pipe gradually contracting and then still more gradually enlarging

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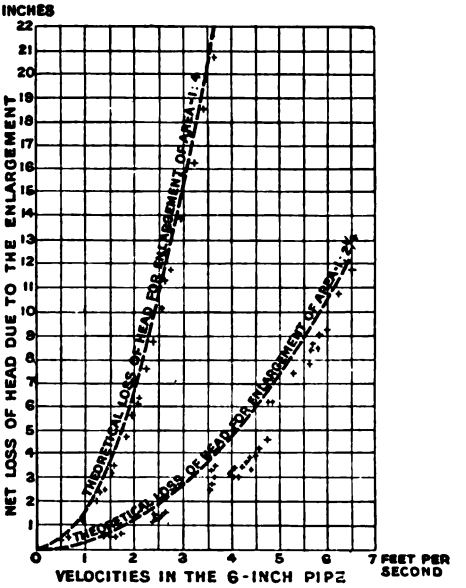
to its original size with the theoretical values for a sudden contraction and enlargement. The results given in Table II

TABLE II.

Contraction and Enlargement.	Velocity of Flow in the 4-Inch Pipe.	Loss of Head in the Contraction.	Loss of Head in the Enlargement.	Total Loss due to the Contraction and the Enlargement.	Value of $2\times\frac{(V-v)^2}{2g}\times 12$
	Feet per Second.	Inches.	Inches.	Inches.	Inches.
5:1	2	1·9	2·0	3·9	23·9
1:5	3	3·7	5·5	9·2	53·7
	4	6·4	9·7	16·1	95·4
	5	11·4	14·7	26·1	149·1
	6	16·6	19·2	35·8	214·7

were obtained from experiments on a 4-inch pipe contracting in 8 inches to one-fifth its normal area and enlarging again to 4 inches diameter in a length of 2 feet 3 inches, the loss in the same length of 4-inch pipe being deducted. It will be seen that, as might be expected, the loss in this case is very considerably less than that given by the theoretical formula for a sudden contraction and enlargement.

Fig. 5.


INCHES
NET LOSS OF HEAD DUE TO THE ENLARGEMENT
THEORETICAL LOSS OF HEAD FOR ENLARGEMENT OF AREA 1:4
THEORETICAL LOSS OF HEAD FOR ENLARGEMENT OF AREA 1:2½
VELOCITIES IN THE 6-INCH PIPE
FEET PER SECOND

NET LOSS OF HEAD AT SUDDEN ENLARGEMENTS OF AREA OF 1 : 2½ AND 1 : 4.

Loss of Head due to Bends.—The loss of head in pipe-bends is a subject which has not been sufficiently investigated, and the results obtained in the following experiments indicate quite different losses from those anticipated.

The following pipe-bends were experimented upon:—In 3-inch pipe, a right-angled elbow and right-angled bends of radii equal to 2, 4, 6,

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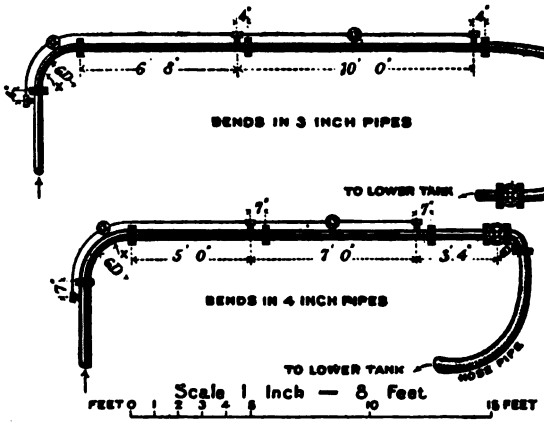
8, 10, 12, and 14 diameters; and in 4-inch pipe, a right-angled elbow and right-angled bends of radii equal to 2, 4, 6, 8, and 10 diameters. Like the straight pipes, these bends were left uncoated and the internal surface was allowed to rust. It was found that most of the loss of head due to the bend does not take place in the bend itself, but in the straight pipe following the bend. Consequently, in measuring the loss of head, a length of straight pipe sufficient for the flow to become normal again was included with the bend, and the normal resistance in a straight pipe equal in length to the bend and this length of straight pipe was subtracted, so that the losses plotted in the curves are the extra losses due to curvature. The arrangements of the pipes for these experiments are indicated in *Figs. 6*; the positions of the experimental bends

Figs. 6.



ARRANGEMENT OF PIPE BENDS.

are denoted by the letter X, and the points at which the pressure-gauges (marked 12 and 13) were connected are shown; at the inlet-end the connection to the gauge was less than 1 foot from the commencement of the bend, but a straight length of 7 feet in the case of both the 3-inch pipe and the 4-inch pipe preceded this connection, and the flow appeared to be practically normal at that section, as indicated by the fact that there was very little difference of pressure between the two sides of the pipe at that point. The length of straight pipe following the bend, the resistance of which was included with that of the bend, was, in the case of the 3-inch pipe, 6 feet 8 inches, and in the case of the 4-inch pipe, 5 feet and 6 feet 7¼ inches, in different experiments. In the former

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the resistance in the succeeding 10-foot length, and in the latter the resistance in a 7-foot length, was also measured, and was found to be constant at a given velocity with the various bends used, and to agree with the loss found in similar pipes in the range of straight pipes. In the case of the 3-inch bends the pipes connected to them were of galvanized iron, and therefore the coefficient for these pipes had to be determined. It was found to be considerably greater than that for the rusted cast-iron pipes and to vary for different velocities, owing to the smoothness of the surface, being greater, as would be expected, for the higher velocities. This variation is allowed for in deducting the resistance of the straight pipe.

TABLE III.—COEFFICIENT FOR GALVANIZED PIPE 3 INCHES IN DIAMETER.

Quantity Discharged.	Velocity of Flow.	Coefficient c in Formula $v = c\sqrt{di}$
Gallons per Minute.	Feet per Second.	
60	3·26	65·2
100	5·43	67·0
150	8·15	68·5
200	10·87	70·0

In the case of the 4-inch bends the straight pipes connected to them were of cast iron and had the same coefficients as those previously experimented upon.

The results of these experiments are plotted in *Figs. 7* and *8*. The velocities of flow in feet per second are plotted horizontally, and the losses of head due to the curvature of the bends are plotted vertically. It will be seen that with a right-angled elbow the loss of head is the same in each case and is equal to $1 \cdot 17 \frac{v^2}{2g}$; i.e., the loss due to a right-angled elbow is independent of the size of the pipe in the cases experimented upon. It will also be noticed that the curves for bends of radii equal to 6 diameters and 8 diameters are steeper than those for bends of either the next smaller or the next larger radius; and in the case of the 3-inch bend of radius equal to 12 diameters, for velocities exceeding 3 feet per second, the flow becomes unstable, the loss of head sometimes being much smaller than would be inferred from the losses in the bends of radii equal to 10 and 14 diameters respectively. In *Fig. 9* the radii of bends in terms of the diameters of the pipes are plotted horizontally, and

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the losses of head vertically, for velocities of flow of 5 feet, 7 feet 6 inches, and 10 feet per second respectively, and for both 3-inch and 4-inch bends. It is readily seen that the losses of head are, in general, rather less for the 4-inch bends than for the 3-inch bends; and also that the loss of head attains a minimum for a radius of 3 to 4 diameters and then increases to a maximum for a radius of 6 to 7 diameters, and finally falls again, irrespective of the velocity. It will be further observed that the loss of head in the bends, in

Fig. 7.

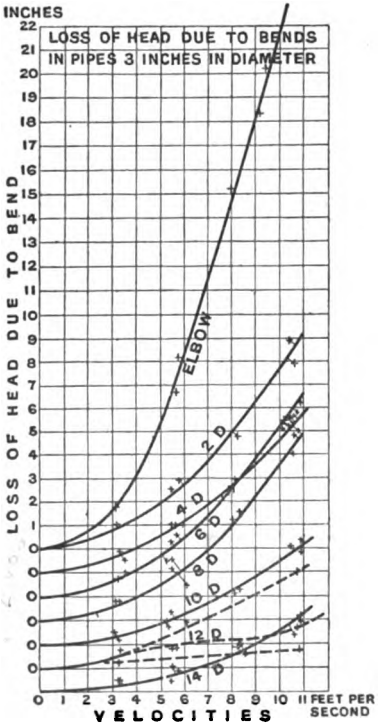
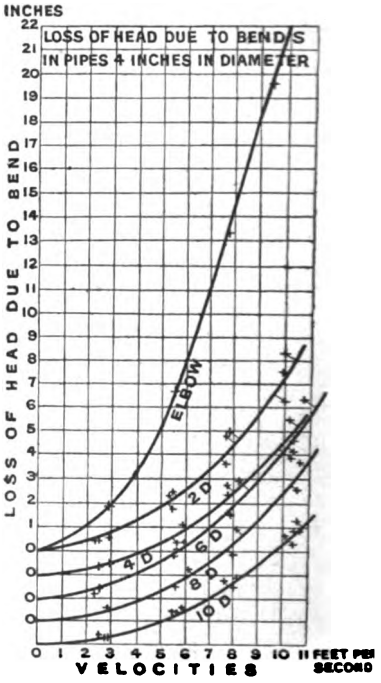


Fig. 8.



each case, varies very approximately as the square of the velocity of flow. It is interesting to compare the foregoing results with those recorded in a Paper read before the American Society of Civil Engineers by Messrs. Williams, Hubbell and Fenkell, "On the Effect of Curvature upon the Flow of Water in Pipes."[1] The diameters of the pipes used in those experiments were 12 inches, 16 inches, and 30 inches, and the maximum losses of head in the right-angled

[1] Transactions of the American Society of Civil Engineers, vol. xlvii (1902), p. 1.

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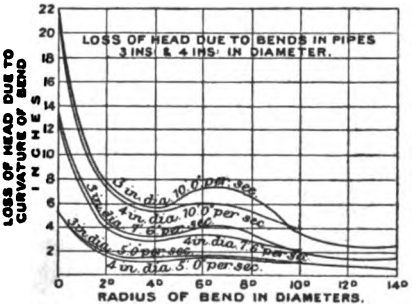
bends included in the investigation are given in the following Table:—

TABLE IV.

Diameter of Pipe (D).	Radius of Bend in Diameters.	Excess Loss of Head due to the Bend measured in Terms of the Resistance[1] of a Length of Straight Pipe.	Coefficient c in Formula $v = c\sqrt{di}$ applying to the Pipe in question.[2] $v = 5$ Feet per Second.	Additional Loss of Head due to Bend for a Velocity of 5 Feet per Second, calculated from the Coefficient in last Column.	Additional Loss of Head due to 4-Inch Diameter Bend. Radius = 4 D (*Fig. 9*). For same Velocity.
Inches.		Feet.		Inches.	Inches.
12	2 D	8·63	66·4	0·6	1·2
12	3 D	18·88 (average of two)	66·4	1·3	1·2
12	4 D	15·28	66·4	1·0	1·2
16	3½ D	26·35	67·2	1·3	1·2
30	2⅔ D	31·40	58·2 average	1·1 average	1·2
30	4 D	34·60	58·2 average	1·2 average	1·2

Bends of four different radii in pipes of 12 inches diameter were experimented upon, the fourth being of sharper radius than the three given in the Table; taking the average of two different results given for the bend of radius equal to 3 diameters, the loss of head shows a tendency to decrease for the largest radius. The loss of head was only investigated for one radius of bend in a pipe of 16 inches diameter, but in the case of the 30-inch pipes the loss of head was measured for bends of six different radii, the largest being 24 diameters, and the results show a continuous increase in the resistance, as the radius of the bend increases, up to the largest radius employed in the experiments. It is obvious that the loss must attain a maximum and then begin to decrease again, because,

Fig. 9.


LOSS OF HEAD DUE TO BENDS IN PIPES 3 INS. & 4 INS. IN DIAMETER.
LOSS OF HEAD DUE TO CURVATURE OF BEND IN INCHES
3 in. dia. 10·0 per sec.
3 in. dia. 4 in. dia. 10·0 per sec.
3 in. dia. 7·6 per sec.
3 in. dia. 5·0 per sec.
4 in. dia. 7·6 per sec.
4 in. dia. 5·0 per sec.
0 2° 4° 6° 8° 10° 12° 14°
RADIUS OF BEND IN DIAMETERS.

[1] Transactions of the American Society of Civil Engineers, vol. xlvii, p. 185.

[2] *Ibid*, p. 187.

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when the radius is infinite, the additional loss due to curvature must be zero. The results of the experiments on the 30-inch bends would appear to show that the maximum loss is obtained with a larger proportional radius in the case of pipes of large diameter, and that the minimum loss for such bends occurs with a rather smaller proportional radius than in the case of the smaller bends employed in the present experiments. From the results given in Table IV, however, the inference may be drawn that, if the radius of the bend is 3 or 4 diameters, taking the smaller radius for larger pipes and the larger radius for smaller pipes, the loss of head due to the curvature of the bend at a velocity of 5 feet per second will not be greater than about $1\frac{1}{4}$ inch, the value for the bend of 4 diameters radius in 4-inch pipes (*Fig. 8*). Since the loss of head is proportional to the square of the velocity, it may be inferred that the loss of head in bends in pipes of any diameter between 4 inches and 30 inches, if the radius be thus chosen, will not be greater than that given for a 4-inch pipe bend of a radius equal to 4 diameters. The method of expressing the loss of head in a bend in terms of a length of straight pipe has obscured this fact, namely, that with bends of the most suitable radius the loss of head is independent of the size of the pipe. It is also misleading to express the loss of head in inches per foot length of the bend, for, at least in the case of short bends, the excess resistance is developed in the length of pipe beyond the bend, as is shown by the following investigation.

In order to ascertain how much of the loss of head actually took place in the bends and how much in the pipe following the bend, due to the rearrangement of the velocities producing an excessive intensity of eddying motion there, it was necessary to measure the energy contained in unit weight of the water as it passed the end of the bend. For this purpose the distribution of pressure and velocity across the end-section of the bend had to be ascertained. In the first instance the difference of pressure at the extremities of the horizontal diameter of that section was measured for the five bends in pipes of 4 inches diameter. The results of these observations are given in Table V, and it will be seen that the pressure was always greatest at the outside of the curve, and that the difference of pressure in some cases was considerable. This suggested that the water moved round the bend more or less in a "free" vortex, i.e., that the energy in each unit weight of water remains constant except for the loss of pressure due to resistance. In order to be able to compare the theoretical values of the difference of pressure at the inside and outside of the bend, on this assumption,

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TABLE V.—LOSS OF HEAD IN THE LENGTH OF THE BEND. PIPE 4 INCHES IN DIAMETER.

1 Radius of Bend in Terms of Diameter (D) of Pipe.	2 Length of Bend and Length of Straight at Inlet-end included with it.	3 Observed Discharge.	4 Velocity of Flow.	5 Measured Difference of Pressure between Outside and Inside of Bend at End.[1]	6 Calculated Difference of Pressure between Outside and Inside of Bend at End.	7 Measured Difference of Pressure between the Inlet Section and the Outside of the Bend at its End Section.	8 Difference between the Mean Pressure at the End Section and the Pressure at the Outside of the Bend there = Col. 5 × $\frac{R_i}{R_i + R_o}$	9 Corrected Value for Difference of Pressure at Inlet to and Outlet from Bend = Col. 7 + Col. 8.	10 Calculated Loss of Pressure in a Length of Straight Pipe = Length of Bend.
	Feet.	Gals. per Min.	Ft. per Sec.	Inches of Water.	Inches of Water.	Inches of Water.	Inches of Water.	Inches of Water.	Inches of Water.
2 D .	1·66	79·2	2·42	0·7	1·1	−0·2	0·3	0·1	0·2
		184·0	5·63	4·3	5·9	−1·1	1·6	0·5	0·9
		263·0	8·04	8·8	12·0	−2·2	3·3	1·1	1·7
		346·2	10·59	15·4	20·9	−3·8	5·8	2·0	3·0
4 D .	2·70	75·7	2·31	0·2	0·5	0·1	0·1	0·2	0·3
		183·3	5·61	1·6	2·9	0·6	0·7	1·3	1·4
		257·7	7·88	3·2	5·8	1·3	1·4	2·7	2·7
		329·7	10·08	5·5	9·5	2·0	2·4	4·4	4·4
6 D .	3·75	80·0	2·45	0·4	0·4	0·3	0·2	0·5	0·4
		180·2	5·51	1·4	1·4	1·3	0·6	1·9	1·8
		264·5	8·09	2·8	4·1	2·9	1·3	4·2	4·0
		337·7	10·33	4·8	6·6	5·1	2·2	7·3	6·5
8 D .	4·80	74·3	2·27	0·2	0·2	0·5	0·1	0·6	0·4
		179·3	5·48	1·0	1·4	2·0	0·5	2·5	2·3
		258·0	7·89	2·2	2·9	3·8	1·0	4·8	4·8
		266·7	8·16	2·0	3·1	4·4	0·9	5·3	5·1
		340·0	10·40	3·6	5·0	6·5	1·7	8·2	8·3
		347·7	10·63	3·4	5·3	7·5	1·6	9·1	8·6
10 D .	5·84	74·7	2·28	0·3	0·2	0·4	0·1	0·5	0·7
		176·0	5·38	1·4	1·1	1·6	0·7	2·3	2·7
		260·5	7·97	3·0	2·4	3·3	1·4	4·7	6·0
		268·7	8·22	3·3	2·5	3·7	1·6	5·3	6·3
		329·3	10·07	5·0	3·8	5·6	2·4	8·0	9·5
		354·0	10·82	5·8	4·4	6·5	2·8	9·3	10·8

[1] The difference between the pressures at the two sides of the pipe, 8 inches from the inlet to the bend on the approach-side (where the pressure was measured), was found to be small. The difference between the pressures at the two sides of any section of the pipe leading from the bend was found to vary at different sections, and from time to time at the same section—sometimes being greater on one side of the pipe and sometimes on the other.

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with the actual measurements, it is necessary to deduce an expression for that difference. It is well known that in a "free" vortex the velocity varies inversely as the radius; thus, if v_o and v_i, p_o and p_i, R_o and R_i denote the velocities, pressures, and radii at the outside and inside of the bend respectively,

$$\frac{v_o}{v_i} = \frac{R_i}{R_o},$$

$$\text{therefore } \frac{v_o}{v_o + v_i} = \frac{R_i}{R_o + R_i} \text{ or } v_o = (v_o + v_i) \times \frac{R_i}{R_o + R_i} \quad . \quad . \quad (1)$$

$$\text{and } \frac{v_i}{v_o + v_i} = \frac{R_o}{R_o + R_i} \text{ or } v_i = (v_o + v_i) \times \frac{R_o}{R_o + R_i} \quad . \quad . \quad (2)$$

Again, by Bernoulli's theorem,

$$\frac{p_o - p_i}{G} = \frac{v_i^2 - v_o^2}{2g}$$

where G = the weight of 1 cubic foot of water.

Therefore, from (1) and (2)

$$\frac{p_o - p_i}{G} = \frac{(v_o + v_i)^2}{2g} \times \frac{R_o^2 - R_i^2}{(R_o + R_i)^2} = \frac{(v_o + v_i)^2}{2g} \times \frac{R_o - R_i}{R_o + R_i} \quad . \quad (3)$$

If v denote the velocity at radius R,

$$\frac{v}{v_o} = \frac{R_o}{R};$$

$$\text{i.e., } v = v_o \frac{R_o}{R} = (v_o + v_i) \times \frac{R_i R_o}{R_o + R_i} \times \frac{1}{R} \quad . \quad . \quad . \quad . \quad (4)$$

therefore the mean velocity $= \bar{v}$

$$= \int_{R_i}^{R_o} v \frac{dR}{R_o - R_i} = (v_o + v_i) \times \frac{R_i R_o}{R_o^2 - R_i^2} \times \int_{R_i}^{R_o} \frac{dR}{R}$$

$$= (v_o + v_i) \times \frac{R_i R_o}{R_o^2 - R_i^2} \log_e \frac{R_o}{R_i}.$$

When the radius of the bend is equal to 2 diameters, this becomes $0{\cdot}96 \times \frac{v_o + v_i}{2}$, and as the radius of the bend increases it gradually approximates to $\frac{v_o + v_i}{2}$;

therefore from (3)

$$\frac{p_o - p_i}{G} = \frac{\bar{v}^2}{2g} \times 4 \frac{R_o - R_i}{R_o + R_i}. \quad . \quad . \quad . \quad . \quad . \quad (5)$$

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From this formula the difference of head between the outside and inside of the bend can be calculated (Table V, col. 6) for the various bends, and compared with the observed results (Table V, col. 5). It may be observed that, since the mean velocity in the bend is proportional to the square root of the difference of pressure between the outside and inside of the bend at the end section, a sharp bend with tube connections from these points to a pressure-gauge such as that described, constitutes a water-metre and involves only a negligible loss of head. The energy due to the velocity will be about the same at the end of the bend as at the commencement, because, although the velocity is not uniform across the sections, its mean value is of course the same. Taking therefore the energy due to velocity to be the same at the end of the bend as at the beginning, the loss of head in the bend will be equal to the difference of the pressure-head at the two ends of the bend. In order to estimate the pressure-head in the water at the end of the bend, it is necessary to know the value of the mean pressure, $\bar{p}$, there; $\bar{p}$ must therefore be found in terms of p_o and p_i.

Let p denote the pressure at radius R;

then $\frac{p}{G} = \frac{p_o}{G} + \frac{v_o^2 - v^2}{2g}$, substituting from equations (1) and (4)

$$= \frac{p_o}{G} + \frac{(v_o + v_i)^2}{2g} \frac{R_i^2}{(R_i + R_o)^2} \left(1 - \frac{R_o^2}{R^2}\right)$$

and $$\frac{\bar{p}}{G} = \int_{R_i}^{R_o} \frac{p}{G} \frac{dR}{R_o - R_i} = \frac{p_o}{G} + \frac{(v_o+v_i)^2}{2g} \times \frac{R_i^2}{(R_i + R_o)^2} \times \int_{R_i}^{R_o} \left(1 - \frac{R_o^2}{R^2}\right) \frac{dR}{R_o - R_i}$$

$$= \frac{p_o}{G} + \frac{(v_o + v_i)^2}{2g} \times \frac{R_i^2}{(R_i + R_o)^2} \times \left\{1 - \frac{R_o^2}{R_o - R_i} \left(\frac{1}{R_i} - \frac{1}{R_o}\right)\right\}$$

$$= \frac{p_o}{G} - \frac{(v_o + v_i)^2}{2g} \times \frac{R_i (R_o - R_i)}{(R_i + R_o)^2}, \text{ substituting from eq. (3)}$$

$$= \frac{p_o}{G} - \frac{p_o - p_i}{G} \times \frac{R_i}{R_i + R_o} \quad \ldots\ldots\ldots \quad (5)$$

This formula enables the pressure-head at the end of the bend to be calculated when the pressure at the outside and the difference between the pressures at the outside and inside of the bend are known. If, therefore, the difference between the pressure-head at the beginning of the bend and $\frac{p_o}{G}$ be measured (Table V, col. 7), the quantity $\frac{p_o - p_i}{G} \times \frac{R_i}{R_i + R_o}$ (Table V, col. 8) must be added to

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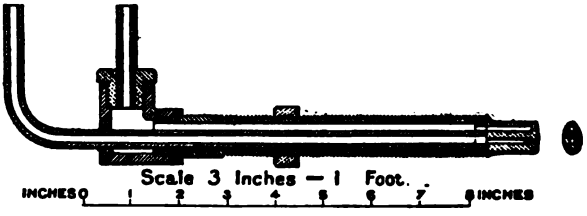
it to obtain the true loss of pressure-head in the bend (Table V, col. 9). It will be seen from Table V that the divergencies between the measured and calculated values of $\frac{p_o - p_i}{G}$ (cols. 5 and 6) are not greater than would be expected from the consideration that the energy per unit volume is not entirely constant at the inlet to the bend, and that head is lost in overcoming the resistance in the bend. It will also be noticed that the losses of head in the bends themselves (col. 9) are not generally greater than the loss in an equal length of straight pipe (col. 10) for the same velocity, and therefore the additional loss of head due to the presence of the bends must take place in the redistribution of the velocities in the pipes following them. From this it may be inferred that the loss of head due to bends deflecting the direction of the pipe through less than a right-angle is not likely to be materially less than for a right-angled bend, unless the angle of deflection is very small. In order to obtain

Fig. 10.



PITOT TUBE.

further evidence as to the nature of the motion of the water in such bends as were experimented upon, the Author decided to obtain comparative values of the velocities across the end-section of one of the bends. The 4-inch pipe bend of a radius equal to 4 diameters was selected for this purpose, as it had proved to be a very representative bend. A small socket $1\frac{1}{2}$ inch in length was screwed into the centre of the cross section of the bend near the end, on the outside of the horizontal diameter, and a small Pitot tube (*Fig. 10*) was screwed through the socket, a water-tight joint being made by a leather washer forced on to the end of the socket by a nut on the threaded body of the tube. The tube consisted of a length of $\frac{1}{2}$-inch gas-pipe, threaded to work through the socket, with an elbow screwed on one end and a plug fitted in the other end. A copper tube, $\frac{3}{8}$ inch in outside diameter, passed through the plug at the inside end and through the elbow at the other end of the pipe. A cap fitted with a length of copper tube was screwed into the free end of the elbow,

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so that india-rubber pipes could be slipped over the extremities of both copper pipes, to connect them to the gauge which was used for measuring the difference of pressures. Soldered to the plug at the inside end of the pipe was a piece of brass, 1 inch in length and elliptical in cross section, its major axis being equal to the diameter of the pipe at the bottom of the thread. A hole $\frac{1}{16}$ inch in diameter was drilled at the extremity of the major axis, at right-angles to the axis of the pipe, near the end, and communicated with the inside of the pipe; that extremity of the ellipse was filed so as to present as sharp an edge to the current as possible. A second hole, of the same diameter, was drilled at right-angles to the first, and communicated with the inside of the internal copper tube. The former of these holes was the velocity-opening and the latter the pressure-opening. It was found, contrary to the Author's expectation, that the velocity, in addition to raising the level of the water in the leg of the gauge connected with the velocity-opening, exerted a suction on the pressure-opening of equal intensity. This was made evident by first causing the velocity-nozzle to face the current and then turning it through an angle of 180° so as to lie away from the current, the pressure opening in each case being at right-angles to the current; the reading in the second case was about half that in the first case, whereas when the velocity-nozzle pointed upwards and the pressure-opening was turned away from the current the reading was zero (Table VI). It will be noticed that the edge at the velocity-opening was comparatively sharp, whilst the surface at the pressure-opening was relatively flat. Thus the difference in the level of the water in the two legs of the gauge corresponded very well with the formula $\frac{v^2}{g}$, and, as for the purpose in question only relative values of the velocities were required, they were worked out from this formula. The velocity-opening could not be placed nearer to the inside of the bend than $\frac{3}{14}$ inch; the readings were therefore taken at this distance from each side and at three intermediate points by removing the india-rubber tubing connecting the openings to the pressure-gauge after each reading, then screwing the Pitot tube across the bend to its next position, and finally replacing the tubing. The velocity through the bend was kept practically constant during the observations by leaving the inlet-valve fully open during each observation and regulating the flow by the outlet-valve, which was not interfered with during the run —the water being cut off whilst the Pitot tube was moved to its new position by closing the inlet-valve. The results obtained are given in Table VI, from which it will be seen that, for the higher

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TABLE VI.—PITOT TUBE OBSERVATIONS AT END OF BEND IN 4-INCH PIPE TO RADIUS OF FOUR DIAMETERS.

Observed Discharge.	Distance of Velocity Nozzle from Inside of Bend.	Observed Difference of Water Level in Legs of Gauge.	$v_i = \sqrt{g\,h_i}$.	$v_o = \sqrt{g\,h_o}$.	$\frac{v_i}{v_o}$	$\frac{R_o}{R_i}$	Remarks.
Gallons per Minute.	Inches.	Inches.					
180	$\frac{3}{14}$	16·0 = h_i	6·55				The distance is measured in $\frac{1}{14}$ths of an inch as there are fourteen threads to the inch on the $\frac{1}{2}$-inch gas-pipe.
	$1\frac{1}{14}$	13·5					
	2	13·5					
	$2\frac{13}{14}$	13·8					
	$3\frac{11}{14}$	9·5 = h_o	..	5·05	1·30	1·28	
252	$\frac{3}{14}$	33·0 = h_i	9·41				[1] This observation was repeated next day on account of this velocity being less than those on either side of it.
	$1\frac{1}{14}$	25·0[1]					
	2	32·0					
	$2\frac{13}{14}$	31·5					
	$3\frac{11}{14}$	21·0 = h_o	..	7·51	1·25	1·28	
241	$\frac{3}{14}$	30·0 = h_i	8·97				[2] The same peculiarity recurs.
	$1\frac{1}{14}$	24·5[2]					
	2	30·0					
	$2\frac{13}{14}$	26·5					
	$3\frac{11}{14}$	18·5 = h_o	..	7·05	1·27	1·28	
	$2\frac{13}{14}$	26·5	..	..	..	..	Velocity-nozzle towards current; pressure-opening pointing upwards.
241	$2\frac{13}{11}$	13·5	..	..	..	..	Velocity-nozzle away from current; pressure-opening pointing downwards.
	$2\frac{13}{14}$	0	..	..	..	..	Velocity-nozzle pointing upwards; pressure-opening pointing away from current.

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velocities, the velocities at the inside and outside of the bend were found to be very nearly inversely proportional to the radii, although the tendency for the velocity in a pipe to be greatest near the centre interfered to some extent with the distribution of velocities near the centre portion of the area. This Table thus affords further evidence that in such bends as those experimented upon the motion of the water approximates to a "free" vortex.

Conclusions.—The results of the foregoing investigations show that the resistance to the flow of water is governed by various conflicting conditions, sometimes one being in the ascendant and sometimes another. In the case of water discharging over weirs, the contraction of the area of flow and the absence of solid boundaries steadies the motion, and it therefore takes place in stream-lines. In the case of flow in rough pipes the friction of the solid boundaries causes the velocity to be greater at the centre than at the sides, and there are therefore cross currents from the sides towards the centre which set up eddying motion, and it is the intensity of this eddying motion which regulates the loss of head. In the case of sudden contractions and enlargements, excessive swirls and eddies occur in the corners which are outside the forward-moving current, causing considerable loss of head. In the case of bends, there is a conflict between the tendency, on the one hand, of the water to flow with the greatest velocity at the centre of the pipe and, on the other hand, to flow as a "free" vortex, with the maximum velocity at the inside of the bend, and these opposing tendencies result in the formation of vortices and eddies which sometimes combine together and reduce the resistance and sometimes oppose each other and increase the loss of head. Thus, at any section of a pipe at which the intensity of eddying-motion is great, there is a continuous variation of pressure though a certain range; consequently the measured loss of head between two sections may be, for an instant, in such cases, 10 per cent. or even 20 per cent. greater or less than the average.

The following is a summary of the results arrived at in the Paper:—

(1) That the flow of water in rusted but not tubercled cast-iron pipes of 3 inches diameter or larger may be expressed by the formula $v = \dfrac{56}{1+\dfrac{1}{40\,d^2}}\sqrt{d\,i}$.

(2) That the actual loss of head at contractions and enlargements shows close agreement with the theoretical values, particularly for a ratio of the areas as great as 4 to 1.

(3) That the additional loss of head in right-angled elbows on

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pipes of 3 inches or 4 inches diameter, due to the deflection of the current through a right-angle, is the same at identical velocities.

(4) That the additional loss of head in right-angled bend pipes of these diameters has a minimum value for bends of a radius equal to four diameters, irrespective of the velocity of flow.

(5) That the additional loss of head in pipes of these diameters attains a maximum for a radius of bend of six or seven diameters and falls again for bends of greater radii.

(6) That the loss of head in right-angled bends of a radius giving this minimum loss is independent of the size of the pipe, and depends only on the velocity of flow and the condition of the internal surface of the pipes.

(7) That the additional loss of head in the case of short bends occurs in the length of pipe following the bend, owing to the intensified eddying-motion there, due to the rearrangement of velocities.

(8) That in the bends experimented upon, the flow tends to approximate to a "free" vortex, the pressure being greatest at the outside and least at the inside of the bend.

(9) The last conclusion is confirmed by the fact that the velocity was found to be a maximum at the inside of the bend and a minimum at the outside, their relative values being approximately inversely proportional to the radii.

The Author desires to express his indebtedness to Mr. Hopps, the superintendent, and Mr. Collett, the assistant superintendent of the Engineering Laboratory at the late Royal Indian Engineering College, Coopers Hill, for assistance in devising the apparatus and carrying out the experiments.

The Paper is accompanied by eight diagrams, from which the Figures in the text have been prepared; and by an Appendix giving the numerical results from which *Figs. 3, 4, 5, 7,* and *8* have been plotted, which may be seen in the library of The Institution.

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(*Paper No. 3672.*)

"Notes on the Arrangements for receiving Importations of Timber at Portishead Dock, Bristol."

By JOHN WILLIAM KITCHIN, Assoc. M. Inst. C.E.

IN this Paper the Author discusses the considerations which led to the adoption of a particular method of dealing with timber at Portishead Dock, and presents some notes on the works constructed.

GENERAL SCHEME.

Particulars of the Dock.—Portishead is in Somersetshire, on the estuary of the River Severn, south of the River Avon, about 2½ miles below Avonmouth and 8 miles from Bristol. Portishead Dock is one of the docks of the Port of Bristol, the others being the Avonmouth Docks, north of the River Avon, and the City Docks, in the heart of Bristol. The dock, which has a water area of 12 acres, was opened in 1879, and was acquired in 1884 by the Corporation of the City of Bristol, who have since administered it through their Docks Committee. The entrance is well sheltered under Portishead Point. The depth of water on the sill is 24 feet at neap-tides, and 34 feet at spring-tides. The lock is 444 feet in length between the gates, and may be closed at either the outer or inner end by a ship-caisson, berthed alongside. The datum for all levels at the port is the sill of the old Cumberland Basin Lock, at the City Docks. The Portishead normal dock-level is 30 feet, and the coping 36 feet, above this datum.

General Development of the Port.—Formerly it was customary for whole cargoes of timber to be delivered both at the Avonmouth Old Dock and at the City Docks, in addition to barge-traffic transferring part-cargoes from the former to the latter. In recent years, however, the development of general traffic at the Avonmouth Old Dock has led to the necessity of providing for all whole cargoes elsewhere, and of extending the timber-yard and sheds there upon land outside the dock proper, which is reached by rail from the quay.

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At the present time timber is brought in liners and discharged overside into barges and sheds, simultaneously with the delivery of general cargo on the quay. There has been a correspondingly large development of general trade in recent years at the City Docks, also requiring accommodation for timber elsewhere. In general, the greater portion of the timber delivered to the port has been mixed cargoes of deals, battens, boards, etc., to which these notes particularly refer.

Preliminary Considerations in laying out the Dock.—It is evident that where a complete cargo is discharged on to a quay, to be dealt with afterwards as a whole, the berth cannot be used by another ship until the accumulated cargo has been removed, and it was desired to avoid this at Portishead by arranging that, on the completion of the discharge of one ship, another vessel might immediately follow into and use the same berth. In the application of machinery for increasing the speed of discharge, it is important to remember that there are certain parts of the work which can be performed best by men. In sorting out lengths, sizes, and qualities, an experienced man can tell at a glance by the brands and marks the quality of any piece of timber, and discrimination of this kind becomes so much a matter of habit that there is very little time lost in the process. The lack of this discrimination in a mechanical contrivance reduces the limit to which machinery can be employed with advantage, and therefore, if machinery is adopted at all, it may be desirable that it should be of such a kind as would be useful for other purposes when not required for expediting discharge or storage. In all the methods of discharging mixed cargoes of deals, battens, boards, etc., in the Port of Bristol, the goods are delivered to the merchant at the ship's rail by hand, in single pieces, by the stevedore's men, whether they are taken out of the ship in single pieces or in slings by the ship's derrick. In either case, whether delivery is made by hand, as for deck-cargoes, or by derrick, as for hold-cargoes, the timbers are put overside with the bottom end resting on the quay and the top end on the ship's rail or other temporary support, and the stevedore's responsibility does not cease until each piece of timber has been lifted by him shoulder-high and received at the shoulder by the merchant's men. Where slings of timber are transferred from ship's derrick to quay crane, the stevedore's men make the transfer. The rate of discharging at Bristol is regulated to some extent by the custom of the port requiring delivery in single pieces at "shoulder-high." This practice means that the speed with which the merchant can accept delivery governs the speed of clearing the cargo. All cargoes,

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however, must be discharged within a limited time, and it has been generally found at the City Docks that the piles are not sufficiently accessible for all the timber to be placed in its final position at once; part of the cargo is therefore laid temporarily in sorted or unsorted stacks on the nearest available space, and is not taken to pile until the ship has gone. Consequently the quay-space alongside the ship is soon absorbed by timber waiting to be piled almost to as great an extent as if the whole cargo had been placed on the quay; and if the space is not long enough to provide berths for other vessels seeking discharge, these must either wait indefinitely till the quay has been cleared or go to some other quay, or even perhaps to another port. If on delivery from the stevedore at the ship's rail each piece could be at once run to pile and laid in its proper place without changing hands, the simplest method of discharge would be attained. This could be done by hand in the case of small deliveries of not very variable goods when the pile is close to the ship, and practically it could be accomplished by machinery in the case of such cargoes as railway sleepers, where the goods are similar and have not to be sorted, in which case the sleepers could be thrown overboard and picked up by a continuous chain with fixed prongs at intervals delivering on to a conveyor. In any case the delivery of single timbers or slings is naturally limited to a somewhat small space near the ship, which may be defined as the "stevedore's delivery-area" or the "receiver's acceptance-area," and which is soon overcrowded by goods and men. If it were possible for this space to be indefinitely extended so that slings might be delivered directly at any point of the yard, there would be no overcrowding, and probably the timber could be placed in pile as fast as the stevedore could throw it out of the ship. Such an arrangement is no doubt too much to hope for, but it indicates that there are two ways of reasonably increasing the speed of discharge to pile, namely, by increasing the speed of running from the ship to the site of the pile, and by enlarging the scope of the "receiver's acceptance-area" to enable goods to be roughly sorted on the ground near the ship, or into wagons, without overcrowding. Both of these features were aimed at in laying out the Portishead yard.

Systems of Working considered.—Turning to recent installations of timber-conveying plant, the "Bolinder" transporter was carefully considered. This consists of a traveller operated by electricity, formed of tractive rollers a few feet apart protruding through the floor of a timber trough which is constructed in sections. Where the berth is suitable and the lead is long, with public

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roads or railways to be crossed, the Bolinder system is understood to serve its purpose satisfactorily, but it was not thought to be suitable at Portishead. Moreover the system is worked with barges, and there will be practically no barge-traffic at Portishead. The reasons for not adopting the Bolinder system apply also to other systems of a like nature, amongst which is the Buchanan conveyor, described in the "Railway Supplies Journal" of 1894. This contrivance is fitted with an endless conveyor-chain and free conical rollers in the floor, placed with their small ends next the chain. The type of conveyor consisting of an overhead endless band carried on rollers as used at Frederickstadt, has given much satisfaction in a situation requiring a considerable lead. Another method, introduced by Mr. E. J. Cullis, Assoc. M. Inst. C.E., is by means of a series of overhead belts carried on stages about 20 feet above the ground, with special platforms for changing the direction of travel, and appliances for bringing the timber to ground at any point. The system of small-gauge trolley-lines at right-angles to the quay, as used at Cardiff, Hull, and elsewhere for conveying pit-props, was also considered. This system is worked by means of light four-wheel trolleys, with platforms about 18 inches above rail-level, carrying an angle-bar cradle some 5 feet or 6 feet in width and of sufficient capacity to hold about forty pit-props. At Cardiff these cradles are filled by means of hydraulic cranes lifting slings directly from the ship. The full trolleys are pushed by two men to the required distance from the quay, where the props are measured and carried away to pile at once, before the trolley is pushed back empty for another load. This method was not thought to be quite suitable for discharging deals and long lengths of timber which have to be lifted at times on to piles more than 20 feet in height. An arrangement of lines with a quick-travelling crane running at right-angles to the quay was carefully considered, and in consultation with the Bristol Timber Merchants it was decided to adopt a system of this kind in laying out the land at Portishead.

Preliminary Accommodation provided.—As preliminary accommodation the Committee decided to equip about 10 acres of piling-ground commanded by quick-running cranes travelling back from a deep-water wharf, sufficient for discharging two vessels at the same time, and connected by ex-ship sidings directly with the Great Western Railway, over which the Midland Railway Company have working facilities. They also decided to provide a jetty for small craft and barges, with a crane for lifting heavy logs, if necessary, from the dock, and a small area of open sheds for dry storage, Fig. 1, Plate 8. The whole of the east side of the dock, amounting to about 40 acres

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in area, and several square miles of farming district eastwards, is on low-lying ground protected from the estuary by earthen embankments. The site brought into immediate use was raised by tipped material and was drained, and the surface was covered with ashes. At the lowest levels dry rubble walls 2 feet in thickness were built up from the original ground to support dunnage-timbers for the piled goods.

Wharf, Piling-Ground, and Quick-running Cranes.—The wharf is constructed of timber; it is 600 feet in length and 32 feet in width, with a depth of water alongside of 24 feet, Fig. 2, Plate 8. Running back from the wharf are nine crane-roads of 4 feet 8½ inches gauge, spaced 67 feet apart, centre to centre. Each crane-road commands ground capable of storing 2½ standards per foot run of crane-road. At present the alley-ways for the cranes are 23 feet in width, but they can be reduced to 20 feet and still leave sufficient clearance between the piled timber and the cranes when these are slewed round. A common width of alley-way in yards worked by hand is 4 feet 6 inches to 5 feet 6 inches, with piling-blocks of 45 to 50 feet, requiring plots of land 50 feet to 55 feet in width for alley-way and storage. The plots are usually numbered by an index-post, and the timber in them is marked with the name of the ship or otherwise for identification. It is, of course, manifest that more of the land can be utilized for storage when worked by hand, but despatch in working with cranes and the fullest economy of the land are not attainable together; and as there is ample space at Portishead, and despatch is desired, this consideration is not so important as it would be in the case of expensive land in a large town. The quick-running cranes can lift a sling of timber weighing 30 cwt., at a radius of 26 feet, at a speed of 160 feet per minute, travel with it at a speed of 600 feet per minute, and place it on the top of a pile 28 feet, but usually worked at 25 feet, in height above rail-level. They change from one crane-road to another over curves of 57 feet radius; these were chosen instead of turn-tables as being likely to give less trouble, but in working they are found to occupy rather more space than is sometimes convenient; and for this reason, had the site permitted, they would have been placed at the extreme end, away from the quay. The wheel-base of the first few cranes purchased was 6 feet, and of the later cranes 5 feet 6 inches, the latter taking the curves with great ease and at a fair speed. The net width of space required for the former when slewing is 19 feet, and for the latter 16 feet. These cranes pick up small stacks of twenty-five to forty pieces of timber—roughly sorted on the quay to size but not to length—and run them away to pile, where each piece is placed as required. The

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timbers are usually placed in separate piles, so that the greatest variation in length in any one pile is about 2 feet. The cranes never carry slings of unsorted sizes from the ship's derrick to the pile. Each quick-running crane is able to keep a gang of pilers continually occupied, and the pilers have to work at high pressure to keep pace with the timber supplied by the cranes. To assist in keeping the quick-running cranes constantly occupied, the "receiver's acceptance-area" is extended into a "receiver's sorting-area" by long-radius cranes on the wharf, one to each ship. These cranes can take slings of timber weighing 30 cwt. directly from the stevedore's ship's derrick at a radius of 44 feet, slew at the rate of 1½ revolutions per minute, and distribute the slings over a sorting-area sufficiently large for the timber to be easily handled. These cranes are also sometimes hired by the stevedores for taking goods out of the holds of sailing-ships. They reach over two sidings which are generally occupied by the railway companies' wagons. By the provision of a "receiver's sorting area," ex-ship sidings, changing-sidings for the travelling-cranes, shunting and other sidings, the piling-ground extends to about 140 feet from the quay-side, as compared with 120 feet at a private wharf at the City Docks where a similar system is adopted; and although at first sight this distance seems to be excessive, in actual practice it is found to be none too great for expeditious handling of the cargo.

When a ship is being discharged, a locomotive is always in attendance, with a large number of wagons, and is standing for part of the time. This suggests that the whole operation might be carried out by means of wagons, the timber being placed directly into the wagons, drawn out, shunted, and lifted and piled by hand, in which case the lines of the yard would probably be laid parallel to the quay instead of at right-angles to it. It is probable, however, that although the number of cranes might be reduced, it would be necessary to provide two or more locomotives to do the shunting. Also it would be necessary to arrange for a sorting-area somewhere away from the quay if trains of wagons were to be filled and removed expeditiously, so on the whole this scheme did not appear to be so suitable as that adopted.

Jetty, Sidings, and Storage-Sheds.—The jetty, which is built of timber, is 200 feet in length and 28 feet in width, with 15 feet depth of water at the outer end, 14 feet depth at one side and 9 feet depth at the other, Figs. 3. It will accommodate four barges, and is placed suitably for any southward extension of the wharf. A 6-ton crane is provided at the outer end, and two lines of sidings run from it, directly connected with the Great Western

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Railway. A nest of sidings is provided at the north end of the site, and various sidings command the whole of the piling-ground and the sheds. The sidings are formed of flat-bottomed rails weighing 70 lbs. per lineal yard, which have proved very satisfactory for the dock-traffic, with locomotives weighing about 30 tons and with tank-engines running at low speeds. The connection of the dock-sidings with the Great Western Railway is designed to suit the exchange of traffic by a double line of rails laid over a small bridge spanning the Portbury stream, with a shunting-neck about 400 feet in length adjacent to the main line. The storage-sheds are of timber, roofed with galvanized corrugated-iron sheets. They are closed at the ends and have open sides protected by over-hanging eaves. They are built in pairs with a covered way between, and are fed on both sides by sidings. The columns are of pitch-pine, set in concrete blocks 15 feet apart, centre to centre, and carry sills 25 feet above rail-level, with queen-post principals 12 feet 6 inches apart, centre to centre, Figs. 4. The most convenient width for these sheds was found to be 44 feet, from centre to centre of the columns. The storage-capacity is about $2\frac{1}{2}$ standards per lineal foot of shed.

Fire-Appliances, etc.—For protection against fire, a floating fire-engine, capable of throwing 350 gallons of water per minute, is stationed in the dock. It is 55 feet in length with a beam of 17 feet and draught of 4 feet. It is fitted with a multitubular vertical boiler working at a pressure of 120 lbs. per square inch, and one horizontal direct-acting pump. A 4-inch water-main is laid round about the piling-grounds and sheds, with fire-hydrants fixed on it in suitable positions and marked by posts painted red with the letter "H" in white upon each. Hose-boxes are provided at several points, each containing 100 feet length of hose and a standpipe having a nozzle $\frac{5}{8}$ inch in diameter. Bucket-stands, each holding twelve buckets of water, are fixed near the sheds. These fire-appliances are in charge of the dock-master, who conducts a practice drill once a fortnight with a squad of men told off for fire-duty.

Construction.

Construction of the Wharf and Jetty.—The timber-piled wharf and jetty do not present any special features of interest, except in regard to the peculiar conditions under which they were carried out. It was stipulated that they should be executed in the dry, but as the traffic in the dock did not admit of the water being lowered sufficiently for this, it became necessary to dam off the site

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to do the work below dock-level. At the same time it was intended that any dams should be constructed at neap-tides, when the dock-level might be lowered a little below the normal. The piles for the jetty, ranging between 48 feet and 60 feet in length, were driven by means of an overhanging travelling-frame starting from the shore and pushed out over each row of piles as they were driven; the overhanging end was counterbalanced and steadied by movable stilts with large flat feet let down on to the dock bottom, Figs. 5 and 6. A small earth dam, made in two compartments, was used at the jetty. The first compartment, enclosing 150 feet length of jetty, was cast up to normal water-level from the excavation between the piles; the remaining 50 feet length, being in deeper water, was formed by extending the bank by tipping from wagons. This little dam had to be continually repaired owing to slips and small leaks. As the excavation proceeded in depth it was planked horizontally on the inside where required and was strutted from the jetty piles. The piles for the wharf, ranging between 48 feet and 58 feet in length, were mostly driven from barges, the remainder being driven from pile-frames on stages as required. On the site of the wharf, at the front row of piles, the depth of water below normal dock-level varied between 6 feet and 12 feet, the dock-bottom being of soft alluvial mud, 35 feet to 45 feet in thickness, overlying hard marl at about 50 feet below normal dock-level.

Details of Wharf-Dam.—At the shallow end of the wharf it had been intended to use an earthen dam, but after the experience gained at the jetty this was abandoned and a timber sheet dam, 6 inches in thickness, was used throughout. As the permanent wharf-piles were driven, the caps were placed on them and a crane-road was laid along the centre-line of the wharf. Movable cantilever logs were clipped on to the permanent caps, and on these were carried two small pile-engines for driving the dam-sheeting, Figs. 7 and 8, Plate 8. The dam was divided into three compartments, the middle part being made first, then the northern or deep end, and, lastly, the southern or shallow end, Figs. 9 and 10. The sheeting-piles for the wharf-dam were of pitch-pine, 12 inches by 6 inches, and in general were 22 feet to 24 feet in length. They were driven about 11 feet, 9 feet, and 14 feet into the mud below the dock-bottom, and passed through depths of water of 12 feet, 10 feet, and 6 feet, for the north, middle, and south compartments respectively. The permanent piles of the wharf are spaced longitudinally 11 feet apart, centre to centre. In forming the dam, first of all a number of king-piles, 12 inches by 6 inches and 24 feet in

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length, with waling-cleats ready spiked on them, were driven 8 feet in front of the wharf 22 feet apart, centre to centre, and to these the upper and lower double walings were attached. The upper walings were 12 inches by 4 inches, their undersides being, on an average, 1 foot above normal dock-level. The double lower walings were 12 inches by 6 inches, the undersides being, on an average, 3 feet below dock-level. A single lowest waling was added on the inside, 7 feet 6 inches below dock-level, as found necessary. Ten sheet-piles were driven on each side of the king-pile, with points splayed towards it. They were driven against wedges, and each one was dogged back on to the walings as it was driven, until a tight-fitting closure-pile could be inserted and driven every 22 feet, midway between the king-piles. A stiffening-pile 12 inches by 6 inches and 24 feet in length was driven close behind the waling at each king-pile and about 6 feet deeper than the king-pile. At the north end, a few of the stiffening-piles were 12 inches by 12 inches and 32 feet in length. The sides of the sheet-piles were coated with a mixture of tar, tallow, and sawdust before being driven, Figs. 11. The main struts and diagonals from the dam to the wharf-piles were from the lower double walings of the dam about 3 feet below normal dock-level; the main struts, 12 inches by 6 inches, were at every wharf-pile; the diagonal struts, 12 inches by 4 inches, were from every king-pile on the dam to every alternate wharf-pile. As the resultant pressure of the full head expected (viz. 9 feet) fell below the main struts, tie-bars $\frac{3}{4}$ inch in diameter connected the upper walings to the wharf at every king-pile of the dam, and were screwed tight alongside small packing-struts to steady the dam until the lowest walings and struts, about 7 feet 6 inches below normal dock-level, could be inserted as found necessary.

In view of the first few feet of the dock-bottom being practically slurry, the general arrangement of this dam seemed at the outset to be barely sufficient, but it was agreed to as it was thought the head against the dam might be controlled by varying the dock-level. During the progress of construction the softness of the dock-bottom was emphasized by the fact that more than one sheet-pile sank to its full depth under the 15-cwt. ram at rest, and in many cases the friction between a pile which was being driven and one already driven carried the latter down further, requiring a number of piles to be dogged together to keep them from sinking too far. When the middle compartment, comprising 230 feet of sheeting, was ready to be pumped out, a pulsometer-pump was set to work and worked for a day without any effect. All visible spaces were

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caulked with oakum, and tighter closures were driven; then two pulsometer-pumps were added, and the three pumps worked together for half a day without lowering the water. A crane-barge carrying a 15-inch centrifugal pump was then brought into use, and, creating sufficient head to make the dam tighten, easily pumped out the compartment. As the water was lowered, ashes were thrown on the outside, to be drawn into the sheeting-joints by the pump-suction, and the joints were caulked with oakum on the inside. When the compartment was emptied, a pulsometer-pump was quite sufficient to keep it dry for fixing the permanent front walings on the wharf-piles, the dock-level being 3 feet 6 inches below the normal, and the head on the dam 4 feet 6 inches.

At the spring-tide which followed the closing of the middle compartment, the dock-level rose to a head of 6 feet 9 inches. This broke through one of the cross-dams, which was made good with bags of clay. The next tide rose to the normal level, giving a head of 8 feet, which caused several "blows" and pushed the dam, with all the wharf-piles in the compartment, over towards the shore. Water was therefore admitted, and was allowed to rise to dock-level. The lock-sluices were opened to lower the dock-level with the falling tide, and for a short time a head of 2 feet was produced inside the dam, partly pushing it back towards its original position; then the pumps were got to work and the water in the dam was lowered till the head was 5 feet 6 inches. The dam was apparently none the worse for its distortion, and directly afterwards, with a head of 5 feet 6 inches against it, an 8-inch pulsometer-pump was able to keep the compartment dry enough for the work to be proceeded with, Figs. 11. At this time the wharf-piles were not braced, and were only connected at the tops by the caps, morticed and dogged. When the dam came to rest, the piles were found to have been pushed shorewards, in groups of four piles joined together by their caps, to the extent of 9 inches at the middle of the compartment, tailing off to 3 inches or 4 inches at the ends. The permanent piles of the wharf were at once temporarily strutted, one to the other, and the back piles were supported by raking struts carried to the shore, from which the groups of piles and the dam were jacked into position again. An additional waling with struts was at the same time placed on the dam about 7 feet 6 inches below normal dock-level. After this, the water was allowed to rise inside the dam on rising tides, and to fall in the dock on falling tides, so as to keep the head at about 5 feet 6 inches.

The north compartment, in 12 feet depth of water, presented a

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somewhat similar record to the middle compartment, but the water was pumped out till the head was 3 feet 6 inches, and this head was maintained while an inner waling was fixed on the dam and several struts were carried from the wharf-piles to the shore. During this work a "blow" occurred under the sheeting. The water was let in and several sheeting-piles were driven about 2 feet further into the mud. On being pumped out again the dam served without further trouble with a head of 5 feet 6 inches against it.

The dam for the south compartment profited by the experience gained on the other two; moreover, the depth of water was only 6 feet, and the mud was stiffer. It gave no trouble at all, and was constructed in a fortnight. In a fortnight more the permanent work within it was completed. When the sheeting-piles and walings of the dam were removed, they were driven as permanent sheeting at the back of the wharf, and the diagonal struts were used for decking bearers. The enclosed space between the wharf sheeting and the shore was filled in with ashes weighing about 11 cwt. to the cubic yard. When the structure of the wharf had been completed the berth alongside was dredged in three cuts. The dredgers used had central well-ladders, and, as their beam did not permit of their dredging within 10 feet of the wharf, the ground inside this area was removed by grab-boats fitted with Priestman grabs delivering into hoppers. The depth of water given was 24 feet at the wharf, and 28 feet at 15 feet from the wharf, below normal dock-level.

Erection of Sheds.—The sheds were not all erected at one time. The erection of the columns and caps of the first shed was performed by means of a light ladder derrick-pole on wheels, moved about as required, travelling first down one side of the shed and then down the other side. This derrick had a hinged strut at the back, which, when travelling, was carried by one man as the ladder was pushed along by another. The principals were erected by means of an ordinary guyed derrick-pole. The remaining sheds were erected progressively from one end by means of a multiple derrick formed of scaffold-poles lashed together and fixed to a framework on wheels, Figs. 12. These poles carried sheaves which were arranged so that the columns and caps on each side of the shed could be lifted, and the principals placed in position complete, in successive operations. The derrick was pulled along by a winch at one end of the shed, and the various members of the shed were erected by means of a number of ropes leading through the sheaves of the derrick and connected with the main rope of the winch as required.

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Conclusion.

Speed of discharging Vessels.—The time occupied in discharging depends to some extent on the number of hatchways in a vessel; with four hatchways four travelling-cranes are used, whilst with three hatchways only two travelling-cranes are employed. The average rate of discharge from ship to pile may be about 50 standards per hatchway per day. In the case of the vessel "Nordstjernen" recently discharged, not having a great variety of goods, 62 standards were discharged and placed in their final position in pile up to 25 feet in height in 8 hours by one travelling-crane. In the case of complete cargoes to be despatched by rail, the rate of discharge has varied between 13 standards and more than 17 standards per hour, delivered from the ship into railway-trucks ready for transit.

Timber dealt with during the First Seasons.—During 1905, the first season, about 6,250 standards of timber goods were dealt with, of which 1,900 standards were sent away directly by rail, whilst in 1906, the second season, the quantity dealt with amounted to more than 10,000 standards.

The work was designed by Mr. W. W. Squire, M. Inst. C.E., Engineer to the Bristol Docks Committee, to whom the Author is Second Assistant. During the construction of the wharf and jetty, Mr. J. W. Goldson, Assoc. M. Inst. C.E., acted as Resident on the works.

The Author desires to express his indebtedness to Mr. Squire for permission to present the foregoing notes, and for kind assistance in their preparation.

The Paper is accompanied by thirteen drawings, from a selection of which Plate 8 has been prepared.

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(*Paper No. 3694.*)

"A Method of Measuring the Extension of Test-Pieces under Tensile Stress."

By Wesley John Lambert, Assoc. Inst. C.E.

Having occasion recently to determine the modulus of elasticity of a special steel, and a mechanical extensometer of sufficient delicacy not being immediately available, it was suggested to the Author by Colonel H. C. L. Holden, F.R.S., that an optical method of measuring the extensions might be devised. The method described in the following Paper is the outcome of this suggestion.

Briefly described, the method consists of measuring upon a screen the optically-projected magnified image of the gap produced by the separation of two knife-edges fastened to the test-piece, the method of projecting the image being in all respects similar to that employed in microphotography. A source of light being placed behind the knife-edges, the gap is magnified under a microscope having a projecting eye-piece and camera-extension, in such a manner that the degree of magnification may be readily ascertained.

The test-pieces used in the determinations were ordinary tensile specimens with screwed ends, 10 inches in length between the shoulders, and 0·564 inch in diameter, which gives a cross-sectional area of $\frac{1}{4}$ square inch. They were accurately ground between centres, and each specimen was critically tested for parallelism and straightness both before and after loading.

Fastened to the shoulder at each end of the specimen was a strip of steel plate terminating in a detachable knife-edge, the two knife-edges being immediately opposite each other, in the same plane, and on one side of the steel strips, *Figs. 1* and *2*. It will be seen that one of the knife-edges is adjustable by means of a screw and slotted hole. This arrangement of detachable knife-edges facilitates the final adjustment of the edges. The two fastening-screws, being held lightly against the test-piece by small elastic bands slipped over the strips and the specimen, also serve as distance-pieces to keep the strips parallel to the test-piece. The method of fastening a stri

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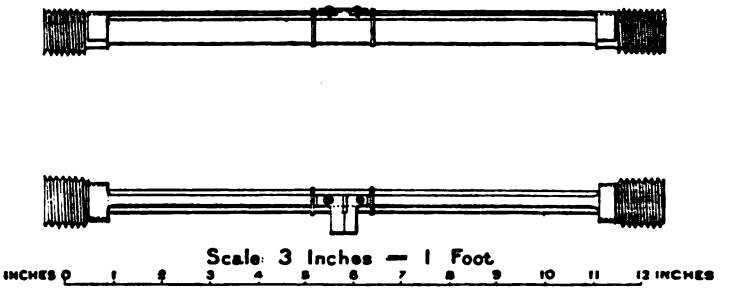
upon the shoulder of the test-piece is by springing the end over the shoulder and securing it by soft solder. By means of fine lines scribed upon the strip and shoulder, it was possible, by subsequent examination, to be assured that no alteration in their relative positions had taken place. This mode of attachment was found to be simple and effective.

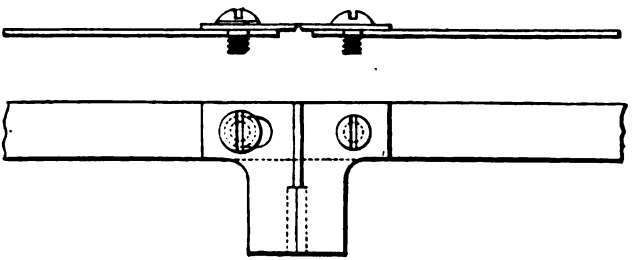
The microphotographic outfit consisted of the ordinary apparatus

Figs. 1.



used in a metallurgical laboratory. The microscope, for convenience, was detached from its stand and was held in a special clip which allowed of adjustment in any direction. Upon the screen (a piece of very finely ground glass), at the rear end of the camera, a sliding vernier was fixed, which enabled the width of the image of the gap

Figs. 2.



to be measured with great accuracy. The magnification was determined by placing a millimetre stage-micrometer exactly in the position occupied by the knife-edges, and comparing the measurements by means of the vernier on the screen, thus ascertaining the extension of the camera necessary to obtain the required magnification.

The actual magnification employed was 100 diameters; thus a gap

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of 0·005 inch was magnified to ½ inch, read off by means of the vernier to thousandths of an inch.

The mode of procedure in making a test is extremely simple. The test-piece having been placed in position in the testing-machine, with the knife-edges properly adjusted, the source of light is focussed on the back of the knife-edges, the gap is carefully focussed upon the screen, and the width of its image is measured by means of the vernier. A known load is then applied, and the width of the image of the gap is again measured. The difference of the two readings gives the extension due to the load applied. This process having been repeated for a series of increasing loads, readings are obtained which enable a stress-strain diagram to be plotted, and the modulus of elasticity of the test-piece to be determined.

By substituting for the screen a photographic plate contained in a dark-slide a photograph of the image of the gap may be obtained.

By the combination of the microscope, camera, and vernier, the extensions can be measured accurately to 0·00001 inch with comparative ease.

The advantages of the method are:—(1) simplicity; (2) the entire absence of mechanical contrivances attached to and working from the specimen; (3) the extreme accuracy with which the extensions can be measured; and (4) the facility with which photographic records may be secured of the extensions resulting from varying loads.

The Paper is accompanied by a tracing from which the Figures in the text have been prepared; and by photographs of the apparatus described, and photographic records taken with it, which may be seen in the Library of the Institution.

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(*Paper No. 3648.*)

"The Analysis of Flue and Exhaust Gases."

By ARNOLD HARTLEY GIBSON, M.Sc., Assoc. M. Inst. C.E.

IN the Report[1] of the Committee of the Institution on "Tabulating the Results of Steam-Engine and Boiler Trials," it is pointed out that an analysis of the flue-gases, and a correct interpretation of the results of that analysis, constitute a most important part of a boiler trial. The general method of collecting and analyzing a sample of the flue-gases is indicated in the Report, and it is not intended in this Paper to deal with that part of the subject, but merely to show how the accuracy of the analysis may be tested, and what interpretation should be put on the results obtained.

Analysis of Flue-Gases.—The possibilities of economizing in the working of a steam-plant by a correct interpretation of the results of an analysis of the flue-gases are so great that, in the Author's opinion, the gas-analyzing apparatus should be as much a part of the equipment of a modern steam-plant as is the steam-engine indicator. As shown in the Committee's Report, the weight of air theoretically necessary for perfect combustion to CO_2 and H_2O of one pound of coal is $11{\cdot}56\ C + 34{\cdot}67\ H$;

or, more correctly, $$11{\cdot}56\left\{C + 3\left(H - \frac{O}{8}\right)\right\}\text{ lbs.},$$

where C, H and O represent respectively the weights of carbon, hydrogen and oxygen in the coal per pound, as obtained by analysis. Also, if the symbols CO_2, CO, O and N be used to represent the proportions, by volume, of each of these gases in the flue-gas, as obtained by analysis, the weight of flue-gases per pound of dry fuel burnt is

$$C\left[\frac{11\,CO_2 + 8\,O + 7\,(CO + N)}{3\,(CO_2 + CO)}\right] + 9\,H\text{ lbs.},$$

[1] Minutes of Proceedings Inst. C.E., vol. cl, p. 218.

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and the weight of air per pound of dry fuel burnt is

$$C\left[\frac{11\,CO_2+8\,O+7\,(CO+N)}{3\,(CO_2+CO)}\right]+9\,H-(1-\alpha),$$

where α denotes the weight of ash per pound of coal.

If, for example, the analysis of the coal be

Carbon	84·0 per cent.
Hydrogen	5·6 „ „
Ash	3·2 „ „
Oxygen (by diff.)	7·2 „ „
	100·0 „ „

the weight of air theoretically necessary for combustion is 11·34 lbs.; while if the analysis of the flue-gas be

CO_2	8·2 per cent.
CO	0·0 „ „
O	11·2 „ „
N	80·6 „ „
	100·0 „ „

the weight of dry flue-gas per pound of dry fuel burnt is 25·45 lbs. The weight of steam present in the flue-gases would be 0·504 lb. per pound of fuel, so that the total weight of flue-gas is 25·954 lbs. per pound of fuel. The weight of air drawn into the furnaces is then (25·954 − 0·968) = 24·986 lbs., so that the weight of excess air per pound of fuel is (24·99 − 11·34) = 13·65 lbs. From these data the amount of heat rejected in the flue-gases, as well as the loss from imperfect combustion of carbon to CO, can be calculated approximately. But the analysis lends itself to more particular dissection than this. Before, however, considering any particular one, it is advisable to know what should be the form of an ideal analysis. Taking the coal analysis already given, the weight of air theoretically necessary for combustion is 11·34 lbs. per pound of coal. If the combustion is perfect and there is no excess of air, the weight of air drawn into the furnaces must be 11·34 lbs. per pound of coal; i.e., since CO = O and O = O,

$$C\left\{\frac{11\,CO_2+7\,N}{3\,CO_2}\right\}+9\,H-(1-\alpha)=11\cdot34.$$

Putting

$$C=0\cdot84$$
$$H=0\cdot056$$
$$\alpha=0\cdot032$$

it is found that $N = 4\cdot47\ CO_2$ (by volume), and since the flue-gas is now supposed to consist entirely of N and CO_2, its composition

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must be 18·3 per cent. CO_2 and 81·7 per cent. N, by volume. This gives the maximum possible percentage of CO_2 for the class of coal assumed. The maximum possible percentage of CO_2 for other coals is given in the following Table:—

Class of Coal.	Composition per Lb.				Maximum possible Percentage of CO_2 by Volume.	Maximum possible Percentage of N by Volume.
	Carbon.	Hydrogen.	Sulphur, Nitrogen, Oxygen.	Ash.		
	Lb.	Lb.	Lb.	Lb.	Per Cent.	Per Cent.
Welsh	0·838	0·048	0·066	0·049	18·45	81·55
Newcastle . . .	0·821	0·053	0·082	0·038	18·35	81·65
Lancashire . .	0·779	0·053	0·122	0·049	18·50	81·50
Scotch . . .	0·785	0·056	0·118	0·040	18·41	81·59
Derbyshire . .	0·797	0·049	0·127	0·027	18·75	81·25
Wayne's Merthyr steam-coal . .	0·878	0·039	0·049	0·034	19·00	81·00
Anthracite . .	0·915	0·035	0·026	0·024	19·21	80·79

This also settles at once the maximum possible percentage of nitrogen, since any excess of air, introducing, as it does, only 79·1 per cent. of its own volume of nitrogen, will lower the total percentage of nitrogen. The case of an analysis showing a greater percentage of nitrogen than is theoretically possible may be due either to an error in the analysis, or to the presence of uncombined hydrocarbons of the olefine class, which, not being acted upon by the reagents employed for absorbing the CO_2, O and CO, will remain and be included with the nitrogen. The percentage of hydrocarbons in most steam-coals, however, is so comparatively small that the error due to this cause is likely to be very small, and to be practicably negligible. The maximum possible percentage of CO will occur when the oxygen and the CO_2 are both *nil*. With the same coal the proportion of CO would then be 28·20 per cent. by volume. The fact that these percentages cannot be exceeded is occasionally sufficient to show the inaccuracy of an analysis, but a more definite check may be obtained in the following manner:—

The weight of CO_2 per pound of dry flue-gas $= \frac{11\,CO_2}{11\,CO_2 + 8\,O + 7\,(CO + N)}$ lbs.

And, since $\frac{8}{11}$ of this was originally oxygen, the weight of oxygen in combination in CO_2 $= \frac{8\,CO_2}{11\,CO_2 + 8\,O + 7\,(CO + N)}$ lbs.

Similarly the weight of oxygen in combination in CO per pound of dry flue-gas . . $= \frac{4\,CO}{11\,CO_2 + 8\,O + 7\,(CO + N)}$ lbs.

The weight of free oxygen per pound . . $= \frac{8\,O}{11\,CO_2 + 8\,O + 7\,(CO + N)}$ lbs.

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In addition, there is the oxygen which has combined with the hydrogen in the coal to form steam, and of which no record is found in the gas analysis.

The weight of this gas per pound of dry flue-gas will be

$$\frac{8\left(\mathrm{H}-\frac{\mathrm{O}}{8}\right)}{\mathrm{C}\left[\frac{11\ \mathrm{CO_2}+8\ \mathrm{O}+7\ (\mathrm{CO}+\mathrm{N})}{3\ (\mathrm{CO_2}+\mathrm{CO})}\right]}\ \text{lbs.},$$

or very approximately

$$\frac{8\ \mathrm{H}\times 3\ (\mathrm{CO_2}+\mathrm{CO})}{11\ \mathrm{CO_2}+8\ \mathrm{O}+7\ (\mathrm{CO}+\mathrm{N})}\ \text{lbs.}$$

The sum of these quantities gives the total weight of oxygen entering the furnace per pound of dry flue-gas, and the nitrogen accompanying this is given by the expression

$$3{\cdot}335\left\{\frac{(24\ \mathrm{H}+8)\ \mathrm{CO_2}+(24\ \mathrm{H}+4)\ \mathrm{CO}+8\ \mathrm{O}}{11\ \mathrm{CO_2}+8\ \mathrm{O}+7\ (\mathrm{CO}+\mathrm{N})}\right\}\ \text{lbs.}$$

But the actual weight of nitrogen as obtained from the analysis is

$$\frac{7\ \mathrm{N}}{11\ \mathrm{CO_2}+8\ \mathrm{O}+7\ (\mathrm{CO}+\mathrm{N})}\ \text{lbs.}$$

So that, if the analysis is correct,

$$(24\ \mathrm{H}+8)\ \mathrm{CO_2}+(24\ \mathrm{H}+4)\ \mathrm{CO}+8\ \mathrm{O}=2{\cdot}1\ \mathrm{N}.$$

Taking into account the fact that $\mathrm{CO_2}+\mathrm{CO}+\mathrm{O}+\mathrm{N}=100$, and combining this equation with the last, the following equation is obtained:—

$$10{\cdot}1\ \mathrm{N}=24\ \mathrm{H}\ (\mathrm{CO}+\mathrm{CO_2})-4\ \mathrm{CO}+800,$$

from which, in the case where $\mathrm{H}=0{\cdot}056$,

$$\mathrm{N}=[79{\cdot}1+\{0{\cdot}133\ \mathrm{CO_2}-0{\cdot}263\ \mathrm{CO}\}]\ \text{per cent.}$$

In the great majority of cases the CO in flue-gases does not exceed 1·0 per cent., so that generally the expression

$$\mathrm{N}=\{78{\cdot}8+0{\cdot}133\ \mathrm{CO_2}\}$$

will provide a check which is quite sufficiently approximate. With coals containing a different percentage of hydrogen and oxygen, these coefficients would, of course, have to be altered; putting

$$\mathrm{N}=\{\mathrm{A}+\mathrm{B}.\mathrm{CO_2}-\mathrm{D}.\mathrm{CO}\},$$

the values for A, B and D, for the coals previously considered, are given in the following Table:—

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Class of Coal.	$\left(H - \frac{O}{8}\right)$	A	B	D	Approximate $N = 78{\cdot}8 + B.CO_2$.
Welsh	0·043	79·1	0·114	0·282	$N = 78{\cdot}8 + 0{\cdot}102\ CO_2$
Newcastle . .	0·046	79·1	0·126	0·270	$N = 78{\cdot}8 + 0{\cdot}109\ CO_2$
Lancashire . .	0·041	79·1	0·126	0·270	$N = 78{\cdot}8 + 0{\cdot}097\ CO_2$
Scotch . . .	0·044	79·1	0·133	0·263	$N = 78{\cdot}8 + 0{\cdot}104\ CO_2$
Derbyshire . .	0·036	79·1	0·116	0·280	$N = 78{\cdot}8 + 0{\cdot}085\ CO_2$
Wayne's Merthyr steam-coal . .	0·034	79·1	0·093	0·304	$N = 78{\cdot}8 + 0{\cdot}081\ CO_2$
Anthracite . .	0·032	79·1	0·083	0·313	$N = 78{\cdot}8 + 0{\cdot}076\ CO_2$

Thus it is seen that where the composition of the coal, or the class of coal, is known, an approximate check on the accuracy of the analysis is available. Obviously, too, from the form of the foregoing result, the percentage of nitrogen is greatest when that of CO_2 is greatest, and diminishes with an increase in the CO.

Types of Analysis.—Although most unusual in practice, the analysis, when obtained, may show that whilst free oxygen is present, yet the amount of air entering the furnace is not in excess of that theoretically necessary for combustion.

In this case, probably the percentage of CO would be high, and the percentage of CO_2 low, indicating a thick fire and an insufficient supply of air through the furnace door, whilst the free oxygen would indicate a considerable admission of air either behind the bridge or by leakage through cracks or openings in the brickwork of the flues. If the nitrogen were also found to be in excess, this would indicate in addition, that the temperature of the furnace was insufficient to decompose the liberated hydrocarbons, which would therefore go to increase the apparent volume of the nitrogen.

The remedy would be to work with thinner fires, with a larger admission of air through the furnace-doors and grate. Probably, too, it would be found that to burn this type of fuel efficiently the size of the combustion-chamber would have to be increased.

In general, however, the analysis will show an excess of air, and a careful examination of the volumetric results will often indicate the steps to be taken to remedy this. With excess of air many types of analysis are possible. An analysis showing a large percentage of CO_2, no CO, and a small percentage of oxygen, e.g.,

CO_2 = 15·5 per cent.
CO = 0·00 „
O = 3·34 „
N = 81·16 „

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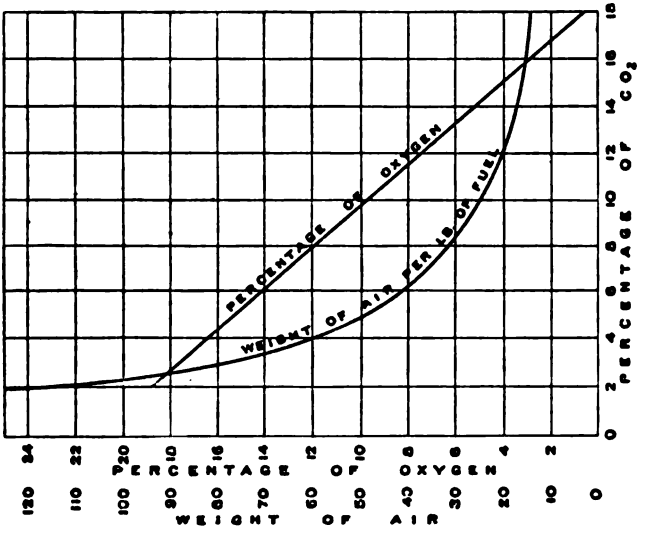
which indicates an air-supply of 16·96 lbs. per pound of fuel, shows a state of affairs which is as near perfection as anything that will ever be obtained in an ordinary boiler-furnace. The Author would emphasize the obvious inaccuracy of such an analysis as the following:—

$CO_2 = 15{\cdot}5$ per cent.
$CO = 0{\cdot}0$ „
$O = 1{\cdot}0$ „
$N = 83{\cdot}5$ „

This is shown by the high percentage of nitrogen, and the failure of the analysis to check, in conjunction with the fact that with such perfect combustion the pressure of any free hydrocarbons would be impossible.

With perfect combustion, as the percentage of CO_2 falls the percentage of free oxygen rises very rapidly. This is shown in *Fig. 1*,

Fig. 1.


PERCENTAGE OF OXYGEN
WEIGHT OF AIR PER LB. OF FUEL
PERCENTAGE OF CO2
0 2 4 6 8 10 12 14 16
21 20 18 16 14 12 10 8 6 4 N
120 110 100 90 80 70 60 50 40 30 20 10 0
PERCENTAGE OF OXYGEN
WEIGHT OF AIR

which also shows, for this particular coal, the relation between the percentage of CO_2 and the weight of air admitted to the furnace per pound of coal, combustion being assumed to be perfect in every case.

A state of affairs very often met with in practice is represented by an analysis of the type

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CO_2 = 8·00 per cent.
CO = 0·00 „
O = 11·84 „
N = 80·16 „

which indicates perfect combustion, but with a large excess of air. If obtained in conjunction with smokeless firing, excessive admission of air through the furnace-doors and grate would be indicated; but if much smoke resulted on firing, the analysis would generally indicate a large leakage of air into the boiler-flues, either through leaks in the brickwork, or through openings at the back of the grate. This type of analysis is particularly likely to be obtained when using a mechanical stoker of the moving-grate type, in which, before the incandescent fuel reaches the back of the grate, the thickness of the fire is so reduced that a large excess of air is admitted through it. Owing to the mechanical difficulty of making moderately air-tight joints, this type of stoker is also particularly liable to leakage at the back of the grate.

An analysis of the type

CO_2 = 6·00 per cent.
CO = 2·82 „
O = 18·00 „
N = 73·18 „

showing a low percentage of CO_2 and of CO with a high percentage of oxygen, and an air-supply of 27·6 lbs. per pound of fuel, would indicate that insufficient air was being admitted over the grate, and an excess of air behind the grate, or by leakage.

In every case the result of an analysis should be considered in conjunction with the special conditions prevailing at the time, in order that a correct deduction may be made. A given analysis, accompanied by the production of dense black smoke, indicating in itself either an insufficient supply of air in the combustion-chamber or a furnace having a combustion-chamber of restricted dimensions, would need a different diagnosis when accompanied by smokeless combustion. But, given a knowledge of the plant and of the conditions of working, a correct diagnosis can be made with great accuracy.

Where an automatic recorder is used, indicating simply the percentage of CO_2 in the flue-gas, the readings from this may be very misleading. Supposing the recorder to indicate, say, 9·0 per cent. of CO_2, this may be accompanied by many varying proportions of CO, O and N. For example, the analyses may be of any one of the types shown in the following Table:—

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	1	2	3	4	5
CO_2	Per Cent. 9·00	Per Cent. 9·00	Per Cent. 9·00	Per Cent. 9·00	Per Cent. 9·00
CO	14·52	10·45	6·38	2·31	..
O	..	3·00	6·00	9·00	10·70
N	76·48	77·55	78·62	79·69	80·30
Weight of air per pound of fuel .	Lbs. 9·96	Lbs. 12·19	Lbs. 15·59	Lbs. 21·49	Lbs. 27·18

The weight of air per pound of fuel corresponding to each analysis is given in the Table, and the weight of air per pound of coal is in each case 11·34 lbs. for perfect combustion. These analyses indicate a very different state of affairs, and very different steps would have to be taken in the five cases to remedy the defects, although from the percentage of CO_2 alone it would probably be assumed that the combustion was fairly satisfactory. If an attempt were made to increase the percentage of CO_2 by admitting more air above the grate to combine with any free CO, with an analysis of type 5 the only effect would be further to dilute the products of combustion without serving any useful purpose. On the other hand, if it were suspected that air was in excess as is usually the case, an attempt to reduce the supply by cutting off air from the furnace, either above or below the grate, would, with analyses of types 1 and 2, at once result in still more incomplete combustion. Whilst useful, as affording a constant check on the steadiness of working, these records, to be of any practical value, should be supplemented by frequent complete analyses of the gases.

Analysis of Waste Gases from Oil- and Gas-Engines.—The increasing use of oil- and gas-engines renders the use of the exhaust-gas analysis as an adjunct to the pressure-volume indicator in diagnosing the conditions of working, increasingly important. Typical analyses of the fuels used in oil-engines are given in the following Table, which shows that these are composed almost entirely of hydrocarbons.

Class of Oil.	C	H	O
Pennsylvania heavy crude oil . .	Per Cent. 84·7	Per Cent. 13·9	Per Cent. 1·4
Russian light oil	86·3	13·6	0·1
,, heavy crude oil	86·6	12·3	1·1
Petroleum, refined	87·1	11·7	1·2

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The products of combustion will, in general, consist of CO_2, CO, O and N, with H_2O in the form of steam, which will not be shown in the gas-analyses. In addition there is usually a quantity of unburned hydrocarbons, which in the analysis will be included with the nitrogen; the percentage of these hydrocarbons will be much greater than in the flue-gases from a boiler-furnace. Whilst the formula previously given can be used to ascertain the weight of air supplied per pound of oil burned, a formula can now be deduced which shall give this independently of the analysis of the oil.

Let CO_2, CO, O and N denote the percentages by volume of these gases given by the analysis of the exhaust-gases. Then, as before, the weight of carbon per pound of dry exhaust-gases

$$= \left\{\frac{3}{11}\text{ weight of } CO_2 + \frac{3}{7}\text{ weight of CO}\right\} \text{ per lb.}$$

$$= \frac{3\,(CO_2 + CO)}{11\,CO_2 + 8\,O + 7\,(CO + N)} \text{ lbs.}$$

If H_2O represent the percentage volume of water-vapour at atmospheric pressure and temperature, which would be found in the exhaust-gases, then weight of C per pound of waste products

$$= \frac{3\,(CO_2 + CO)}{11\,CO_2 + 8\,O + 7\,(CO + N)} \left\{\frac{100}{H_2O + 100}\right\} \text{ lbs.}$$

Also the weight of hydrogen per pound of waste products

$$= \frac{1}{9}\text{weight of } H_2O = \frac{\frac{H_2O}{2}}{11\,CO_2 + 8\,O + 7\,(CO + N)} \left\{\frac{100}{100 + H_2O}\right\}$$

(since the molecular weight of H_2O is 18).

Therefore the weight of oil (C + H) per pound of waste products (neglecting the small percentage of oxygen in the oil)

$$= \frac{3\,(CO_2 + CO) + \frac{H_2O}{2}}{11\,CO_2 + 8\,O + 7\,(CO + N)} \left\{\frac{100}{100 + H_2O}\right\}$$

Again the weight of oxygen per pound of waste products

$$= \frac{8}{11}\,(\text{weight of } CO_2) + \frac{4}{7}\,(\text{weight of CO}) + \frac{8}{9}\,(\text{weight of } H_2O) + O$$

$$= \frac{8\,CO_2 + 4\,CO + 4\,H_2O + 8\,O}{11\,CO_2 + 8\,O + 7\,(CO_2 + N)} \left\{\frac{100}{100 + H_2O}\right\}$$

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And the weight of nitrogen per pound of waste products

$$= \frac{7\,N}{11\,CO_2 + 8\,O + 7\,(CO+N)} \left\{ \frac{100}{100+H_2O} \right\}$$

$$= 3{\cdot}335 \text{ (weight of oxygen per pound).}$$

Therefore $$\frac{7\,N}{3{\cdot}335} = 8\,CO_2 + 4\,CO + 4\,H_2O + 8\,O,$$

from which $$H_2O = 0{\cdot}525\,N - 2\,CO_2 - CO - 2\,O.$$

So that the weight of oil per pound of waste products

$$= \frac{2\,CO_2 + 2{\cdot}5\,CO - O + 0{\cdot}2625\,N}{11\,CO_2 + 8\,O + 7\,(CO+N)} \left[\frac{100}{100+H_2O} \right]$$

Therefore the weight of air per pound of oil

$$= \frac{\frac{4{\cdot}335}{3{\cdot}335} \times 7\,N}{2\,CO_2 + 2{\cdot}5\,CO - O + 0{\cdot}2625\,N} \text{ lbs.}$$

$$= \frac{36{\cdot}36\,N}{8\,CO_2 + 10\,CO - 4\,O + 1{\cdot}05\,N} \text{ lbs.}$$

So that if the oil-analysis be known, the weight of excess air per pound of oil can now be determined. This assumes that no uncombined hydrocarbon is to be found in the nitrogen.

If the whole of the hydrocarbons be not combined, and if N′ be the percentage volume of (nitrogen + hydrocarbons) the weight of air per pound of oil can be shown to be

$$\frac{36{\cdot}36\,(N'-x)}{8\,CO_2 + 10\,CO - 4\,O + 1{\cdot}05\,(N'-x) + ax} \text{ lbs.,}$$

where x denotes the percentage by volume of uncombined hydrocarbon in the waste gas,

and a the molecular weight of this hydrocarbon × weight of carbon per lb.

If this uncombined hydrocarbon be taken to be mainly marsh-gas (CH_4), its molecular weight is 16, and $a = 12$, so that the foregoing expression reduces to

$$\frac{36{\cdot}36\,(N'-x)}{8\,CO_2 + 10\,CO - 4\,O + 1{\cdot}05\,N' + 10{\cdot}95\,x} \text{ lbs.}$$

Assuming combustion to be perfect, and just sufficient air to be admitted, then $CO = O$ and $O = 0$, while $N' = N$; so that the

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expression becomes:—Weight of air per pound of oil for perfect combustion

$$= W_a = \frac{36{\cdot}36\ N}{8\ CO_2 + 1{\cdot}05\ N}$$

and since $CO_2 + N$ is now 100, this may be written

$$W_a = \frac{36{\cdot}36\ N}{800 - 6{\cdot}95\ N}$$

$$= \frac{36{\cdot}36\ (100 - CO_2)}{105 + 6{\cdot}95\ CO_2}.$$

Thus with the oil-analysis

$$C = 0{\cdot}8471$$
$$H = 0{\cdot}1390$$
$$O = 0{\cdot}0139$$

the value of Wa for perfect combustion is 14·55 lbs.; so that

$$\frac{36{\cdot}36\ (100 - CO_2)}{105 + 6{\cdot}95\ CO_2} = 14{\cdot}55.$$

Therefore $CO_2 = 15{\cdot}33$ per cent.,

and $N = 84{\cdot}66$ „

This gives the maximum possible percentages of nitrogen and of CO_2 in any such analysis, a higher value of N in general indicating either faulty analysis or the presence of uncombined hydrocarbons.

The maximum possible percentages of CO_2 and of N with oils of various compositions are given in the following Table:—

Oil.	C	H	O	No excess Air, but Combustion complete.	
				Maximum Percentage of CO_2.	Maximum Percentage of N.
				Per Cent.	Per Cent.
American crude petroleum .	0·8471	0·1390	0·0139	15·3	84·7
„ refined petroleum .	0·8660	0·1230	0·0110	16·0	84·0
Russian crude oil	0·8710	0·1170	0·0120	16·1	83·9
„ refined oil . . .	0·8630	0·1360	0·0140	15·2	84·8

Except to this extent this formula does not provide a check on

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the results of an analysis, but these can always be checked very approximately by the formula used for flue-gas analyses.

Since

Hydrogen	combines with oxygen at		1,124° F.
The olefines (C_6H_4)	„	„	1,124° F.
Marsh-gas (CH_4)	„	„	1,201° F.
CO	„	„	1,347° F.

it would appear to be very probable that the temperature reached in all parts of the cylinder of an oil-engine during the explosion-stroke is sufficient to decompose all the hydrocarbons, and that if any hydrocarbon should remain uncombined it would be marsh-gas. Owing, moreover, to the avidity with which nascent hydrogen combines with oxygen, and to the fact that the combination takes place at a temperature lower than that of the combination of either CH_4 or CO, it is unlikely that any hydrocarbon except a small percentage of marsh-gas will be found in the exhaust-gases, except where the air-supply is very restricted, and the percentage of CO is in consequence high. The weight of unconsumed hydrocarbon, if any, per pound of exhaust-gases, can be calculated in the following manner :—

The proportion by weight of free oxygen in the waste gases, together with the nitrogen accompanying this as air,

$$= \frac{4{\cdot}335 \times 8\,O}{8\,O + 11\,CO_2 + 7\,(CO + N) + 4\,x.}$$

This gives the proportion of free air in the waste gases. The weight of air necessary for combustion being known, and that actually present being calculated, the difference gives the excess by calculation, from which the percentage excess may be calculated. If, on neglecting x, these two values of the percentage excess are identical, there is no uncombined hydrocarbon in the waste gases; but if the first value is in excess of the second, the presence of uncombined hydrocarbon is indicated. The real weight of air in excess is obtained by multiplying the value obtained in the ordinary way by the ratio of these values, and the weight of air actually entering into combination can then be determined. Let this be denoted by W. If then C^1 and H^1 be the weights of carbon and hydrogen actually entering into combination per pound of oil,

$$W = 11{\cdot}56\,\{C^1 + 3\,H^1\}.$$

Assuming the uncombined hydrocarbon to have the composition CH_4, the weight of C per pound of uncombined hydrocarbon is

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0·75 lb., and the weight of hydrogen 0·25 lb. If then w is the weight of CH_4 per pound of fuel,

$$C^1 = C - 0{\cdot}75\,w,$$

and

$$H^1 = H - 0{\cdot}25\,w,$$

so that with oil having $C = 0{\cdot}8471$,

and $H = 0{\cdot}1390$,

$$0{\cdot}8471 - 0{\cdot}75\,w + 3\,(0{\cdot}139 - 0{\cdot}25\,w) = \frac{W}{11{\cdot}56},$$

$$\text{i.e., } 1{\cdot}5\,w = 1{\cdot}264 - \frac{W}{11{\cdot}56},$$

from which w can be determined when W has been calculated.

The checking formula for these gases, obtained as in the case of the boiler flue-gases, has the following constants for different oils:—

Oil.	A	B	D
American crude oil	79·1	0·330	0·065
„ refined oil	79·1	0·278	0·118
Russian crude oil	79·1	0·292	0·103
„ refined oil	79·1	0·323	0·072

where, as before, $N = A + B\,CO_2 - D\,CO$.

This formula is applicable only when all the hydrocarbons are consumed. If an excess of nitrogen is shown by the analysis, the weight of uncombined hydrocarbon corresponding to this may be calculated as just shown. The percentage volume x of this, and consequently the true percentage N of nitrogen, can now be obtained. The checking formula becomes $N = A + B.CO_2 - D.CO - 0{\cdot}495\,x$, where A, B, and D have the values already given.

Exactly the same reasoning applies to the case of the flue-gases from a furnace using oil-fuel. In the case of a gas-engine using producer-gas of known composition, the percentage of N and of CO_2 in the waste-gas analysis will, of course, be affected by the fact that these gases are also present in the producer-gas; but a formula can easily be deduced on the same lines as that for the combustion of oil-fuel, which will make allowance for these factors.

The Paper is accompanied by a diagram, from which the Figure in the text has been prepared.

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(*Paper No. 3692.*)

"Munaar Valley Electrical Power Scheme."

By RICHARD FENWICK THORP, M. Inst. C.E.

OWING to the steady increase in the yield of leaf on the tea estates of the Kanan Devan Hills Produce Company in North Travancore, South India, the power available at several of the Company's factories has been inadequate to deal with the manufacture.

To meet the demand for extra power the Author proposed that the power available at the Pullivasal falls on the Munaar river (situated about 2½ miles below Munaar, the headquarters of the Company) should be turned to account, by erecting a power-station at the foot of the falls and transmitting the power to the several factories by electricity. After due consideration the directors sanctioned the scheme in June, 1904. The plans and indents for the necessary plant were prepared and sent home, and the contracts for the hydraulic and electrical plant were let in April and May, 1905. The construction of the water-channel, power-house and other necessary buildings was put in hand in March, 1905. The whole installation, with the exception of the transmission line to one factory, was completed by the beginning of May, 1906. This fifth transmission line was completed by the end of July.

It was decided to furnish three factories, namely, Sevenmallay (1¾ mile from the power-station), Nallatanni (3¼ miles from the power-station) and Periavurray (4 miles from the power-station) with only 20 HP. each, as the existing water-power at these factories was sufficient to deal with the manufacture except in the dry months of the year, that is, from December to the beginning of June. The existing water-power plant at Munaar (2 miles from the power-station), the largest factory in the district, could not satisfactorily cope with the manufacture even when assisted by a 10-HP. steam-engine. It was therefore decided to provide a 50-HP. electric motor for this factory and transfer the steam-engine elsewhere. The old water-power plant was retained as a stand-by in the event of

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failure of the electrical plant. Although the Letchmie factory (3½ miles from the power-station) was provided with ample steam-power, it was decided to work it by means of a 50-HP. electric motor, it being estimated that a saving of Rs.3,000 (£200) per annum would thereby be effected in fuel alone. Moreover, the steam-engine would then be available for transfer to one of the Company's factories, many of which are too remote from the power-station to be economically supplied with electric power. The minimum amount of power required for the five factories above mentioned is 160 HP.

It was decided to adopt the three-phase alternating-current system, at 2,200 volts, and, allowing for a drop of 10 per cent. on the line, to transform at the factories from 2,000 down to 200 volts. Tenders were invited in England for two units, each consisting of one 75-kilowatt generator direct coupled to a 120-HP. hydraulic turbine; each turbine to be served by a separate 12-inch pipe. The tenders for the generators included factory motors and transformers, all the switch-boards, fittings, and the line wire and insulators.

Description of the Munaar River.—The Munaar river is fed by three main branches, namely, the Kundale river, rising in the extreme north-east corner of the Company's lands near the top of the Kotagudi[1] ropeway, which, after a course of about 20 miles, joins the second main branch, the Nyamakaad river, at Munaar. This latter river has its source near the top of Aniemudi mountain, 8,864 feet above sea-level, and about 8 miles due north of Munaar. The third main branch, the Sevenmallay river, is about 8 miles long, and rises in the south-west corner of the Company's land. The two rivers first mentioned contributed about equal quantities of water to the main stream, the rainfall on the smaller catchment area (15 square miles) of the latter being much heavier than that on the first, which is about 60 square miles. The supply from the Sevenmallay river is comparatively small except in flood time. The minimum discharge of the Munaar river at the Pullivasal falls is taken by the Author at 50 cubic feet per second, that being the lowest dry-weather supply during the last 8 years. The discharge of the maximum flood during the same period he estimates at 12,000 cubic feet per second. The whole catchment area, some 85 square miles in extent, consists of steep valleys, and the bed-fall of the main rivers is generally steep; for instance, the average fall of the Kundale is 100 feet, and that of the Nyamakaad 200 feet to the mile, exclusive of the upper 3 miles, where the latter river runs down the precipitous face of Aniemudi mountain.

[1] Minutes of Proceedings Inst. C.E., vol. clxi, p. 332.

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The Munaar river runs through a steep gorge in the hills about 2 miles below Munaar, and from this point there is a succession of rapids to the head of the Pullivasal falls, where it flows over an almost perpendicular cliff 300 feet high; the river then continues its course over rapids to the low country. Munaar is 4,800 feet and the power-station is about 3,800 feet above sea-level. The whole catchment area receives the greater part of its water-supply during the south-west monsoon, when the whole western side of the district is exposed to extremely heavy rain from the beginning of June to the end of August. Some rain also falls from September until the middle or end of December. The annual rainfall on this portion of the district averages 250 inches. The rainfall on the eastern portion of the catchment area is lighter and averages only 100 inches per annum. The average over the whole catchment area ranges probably from 180 inches to 220 inches per annum.

January, February, March and first half of April are the dry months of the year in which practically no rain falls, but the greatest scarcity of water occurs after the first rains have fallen at the end of April and the beginning of May. A few days after the first heavy showers, the water-supply of all the streams falls very rapidly indeed; in some instances the Author has gauged a diminution of flow of as much as 40 to 50 per cent. in the course of a few days. In one instance a small stream feeding a lake for supplying power to one of the factories, and which was able to keep the water in the lake high enough to deliver 100 cubic feet per minute to the water-course for 10 or 12 hours per day all through the dry months, failed within 4 days of the first heavy showers in the beginning of May, and the situation was not relieved until the monsoon set in at the beginning of June, although 3 to 4 inches of rain had fallen between the first showers in May and the burst of the monsoon in June. The Author attributes this fact to the absorption of the underground waters, which feed the streams, by the suction set up by the surface soil becoming wet and then being again subjected to the heat of the sun. When the surface soil is thoroughly dry it prevents the subsoil waters from being evaporated, but when the surface soil is damped by the early rains, the evaporation of this damp causes a partial vacuum and draws up some of the subsoil waters and thus lessens the supply available for feeding the streams. Unfortunately the heavy showers in the beginning of May bring on the greatest flush of tea, and, therefore, it is just when the factories have the most leaf to deal with that their supply of power is at its lowest.

Water-Channel.—The water-channel is 1,100 feet long and carries

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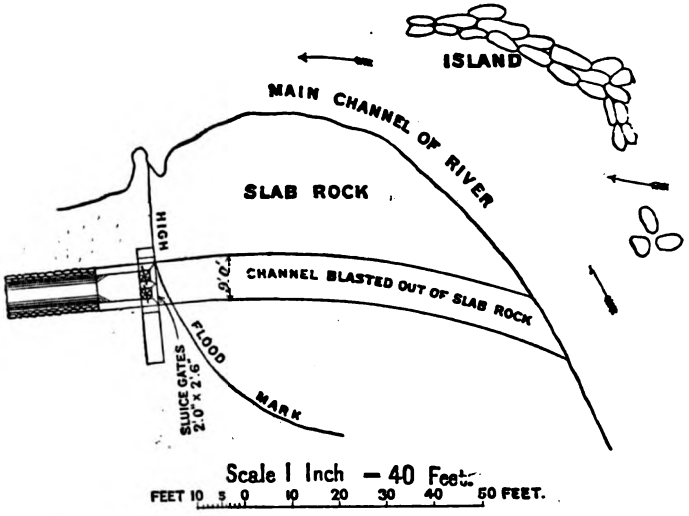
the water from a point just above the lip of the Pullivasal falls, where there is a suitable site for the intake, to a point vertically above the power-house. The intake was formed by blasting a channel 8 feet wide and 3 feet 6 inches deep through the slab rock forming the river bed, and thus the necessity of building a dam across the river was avoided. Not only was a great saving in first cost effected, but the continual danger of the intake being injured by the high floods experienced on this river in the south-west monsoon was avoided, when the rainfall on portions of the catchment area sometimes amounts to 17 inches in one day.

Just above the intake the river bifurcates, passing on each side of a small island (*Fig. 1*) in the middle of the river, and joins again

Fig. 1.



below the intake. The channel furthest from the intake is practically dry except in flood time. Some large boulders were blasted out of this channel to relieve the main or left bank channel, on which the intake is situated, in order to reduce the risk of the intake sluices being flooded, should the river at any time rise above the present recorded maximum flood-levels. This precaution was taken as it is impossible to foresee from previous records to what level these mountain torrents may rise. The intake is provided with two sluice gates situated at a point about 100 feet from the actual intake and out of reach of the main force of the current, even in the highest floods. The land on which the water-channel is built is

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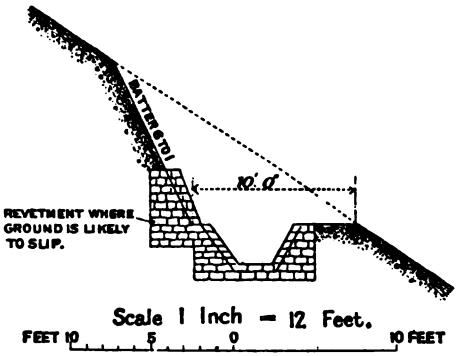
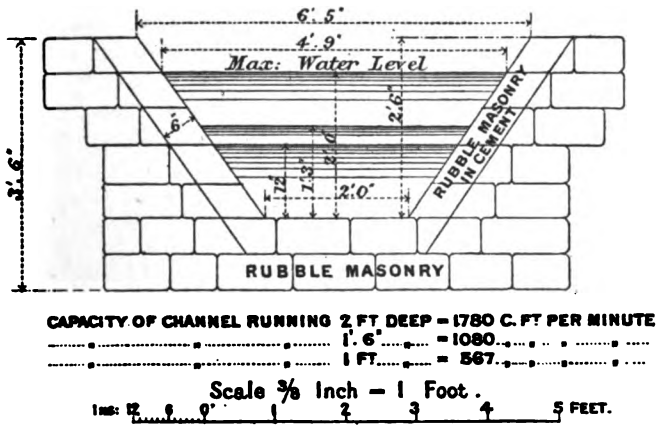
steep (*Fig. 2*) and rough, having a side slope of about 2 to 1. A road 10 feet wide was first cut out of the hillside and a trench for the water-channel was excavated 7 feet wide and 3 feet 6 inches deep. This trench was then lined with rough dry stone masonry built to

Fig. 2.



the proper gradient and profile, and the perimeter was then run in and plastered with 4 to 1 cement mortar. In only two places was it found necessary to take the foundations of the side walls below the bottom of the trench. The gradient of the channel is 1 in 300,

Fig. 3.



the bottom width being 2 feet and the depth 2 feet 6 inches, as shown in *Fig. 3*. The maximum safe discharge of the channel is calculated to be 1,800 cubic feet per minute. The channel was built to these dimensions to allow for future extensions of the scheme.

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In two or three places where the sidelong slope of the ground is steep the channel is covered in with jungle trees and rough planking to prevent it from injury by any small slips that might occur in the wet weather.

The head tank was formed by blasting a channel 8 feet wide and 110 feet long in the rock, and two overflow weirs are provided at slightly different levels; the surplus water flowing over them runs down the slab rock to the river. The first part of the head tank, 46 feet in length, and about 8 feet by 2 feet 6 inches in section, is furnished at its lower level with a low baffle-wall, and can be cleaned by means of two scour-pipes. An iron grid with 2-inch spaces is fixed just beyond the baffle-wall to catch sticks, etc., and a wire screen of $\frac{1}{2}$-inch mesh is fixed across the bell-mouths of the service-pipes which lead from the end of the tank, 80 feet beyond the baffle-wall. It is found that no sand passes over the baffle-wall, and that the water entering the pipes is exceptionally free from solid matter even when the river is in flood, a matter of great importance, as the smallest particles of solid matter seriously interfere with the working of the hydraulic governors of the turbines.

The depth of water in the channel when supplying the present plant (i.e. two turbines of 120 HP. each) is 10 inches.

The total cost of the water-channel, including intake, sluices and head-tank, was about Rs.6 8a. (8*s*. 8*d*.) per lineal foot. The cost of cement was £6 15*s*. per ton, owing to the heavy expense of transport.

The Pipe-Line.—The pipe-line (*Fig. 4*) is 800 feet long and falls 392 feet. The pipes are laid over steep slab rock for almost the whole of the length. There are two 12-inch steel pipes $\frac{5}{16}$ inch thick laid side by side with just sufficient room between them to allow a spanner to be used to tighten up the bolts in the joints. The pipes are of welded mild steel and are fitted with loose cast-iron flanges, each having 10 bolts, 1 inch diameter; the joints are made with rubber insertion-washers which are held in place by the recess of the female flange. Two types of bends were used, one of 45° and the other of 30° off the straight. To enable the direction of the pipe-line to be slightly altered, cast-iron tapered washers of various angles were provided. These were found to be a great convenience, in fact, it would have been almost impossible to erect the pipes without them, as the country is very rough and broken; and it would have been very expensive to have attempted to lay the pipes to an even gradient on account of the rocky nature of the ground. The larger hollows were built up with rough stone revetments, and rough stone pillars were built at 20-foot intervals to support the pipes. Both pipes were anchored to concrete blocks

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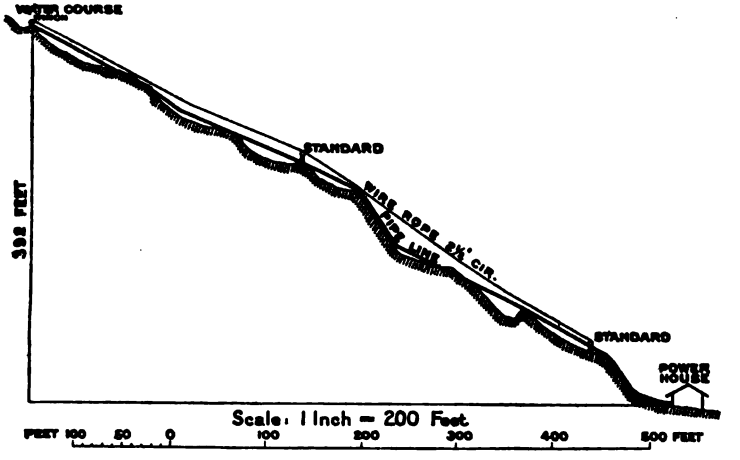
near the power-house, and were also fixed to the slab rock in many places with iron straps secured by lewis bolts. The pipes are provided with bell-mouths. Where the pipes pass through the wall of the head tank a rough stuffing-box was formed around them in the masonry and was packed with tarred sacking. This arrangement was adopted so that the pipes could slide in the wall, when contracting or expanding, without cracking the masonry. Other expansion joints were considered to be unnecessary on account of the many bends in the pipe.

The method of erection was as follows:—A 2½-inch wire rope was anchored to a post near the bottom of the pipe line, and its other end was attached to the drum of a winch fixed at the head tank.

Fig. 4.



The pipes, having been delivered at the head tank, were attached to runners resting on the wire rope and were lowered down to where they were required by means of a hemp rope. When the wire rope was too far above the ground to allow of a pipe being deposited exactly where it was required, it was slackened by means of the winch and the pipe was lowered into place. The cost of erection of the two pipes, including clearing the site, rough stonework, red lead, and labour, etc., was 3*s.* per lineal foot of double pipe.

The Hydraulic Machinery.—The water turbines consist of a modified form of Pelton wheel, and are each capable of developing 120 HP. at 500 revolutions per minute under an effective head of 380 feet, and require 220 cubic feet of water per minute. Each wheel is 3 feet in diameter on the centre line of the buckets, and

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the nozzle, when fully open, is $2\frac{3}{8}$ inches diameter. The buckets are of the usual type divided by a central rib, and are attached to the rims of the wheels by bolts.

The supply of water to the wheel is regulated by a spear working in the nozzle, and actuated by means of a hydraulic governor. The rod of the spear is fitted with two pistons, the lower and smaller one is under the pressure of the water in the service-pipe, and tends to raise the spear and open the nozzle. The upper and larger piston tends to press down the spear and close the nozzle, and is acted upon by water which passes through a valve controlled by a centrifugal governor. The water for the governor valve is led from the service-pipe near the nozzle by a small copper pipe provided with a simple gauze filter. The damping effect necessary to prevent the "hunting," which occurs in all hydraulic governors, is obtained by means of a small lever which bears against the surface of a revolving cam on the governor spindle. This lever acts on the governor valve and tends to prevent the supply of water to the wheel being cut off too suddenly when the speed suddenly increases. The action of this lever also keeps the valve of the governor moving up and down when the turbine is running at its normal speed, and thus helps to prevent this valve from sticking. This governor works fairly well and can be adjusted to regulate the turbine with great accuracy, provided the water is absolutely free from solid matter, but even the most minute particles are sufficient to cause the governor-valve to stick. As already stated, however, the water is exceptionally clean, even when the river is in flood, and practically no trouble is experienced so long as the machines are running. When, however, the turbines have been shut down for some time the minute particles of solid matter in suspension in the water settle at the bottom of the service-pipes near the sluice valve, and when a turbine is started these particles occasionally pass through the filter, and cause the governor valve to stick, and trouble is experienced until the turbine has been running for half an hour or so. This trouble could be obviated by fixing a blow-off tap, say of 2 inches bore, at the bottom of the service-pipe outside the main sluice-valve, so that all the dirty water lying in the pipe might be blown out before starting. A small scour-tap is provided at the filter, but, although it cleans the filter, it does not prevent the smaller particles of dirt from being forced through the gauze. A larger and more effective filter might be with advantage provided for governors of this class.

The governors were specified to control the speed of the turbines so that there would be no perceptible increase of speed when

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10 per cent. of the load is suddenly thrown off, not more than

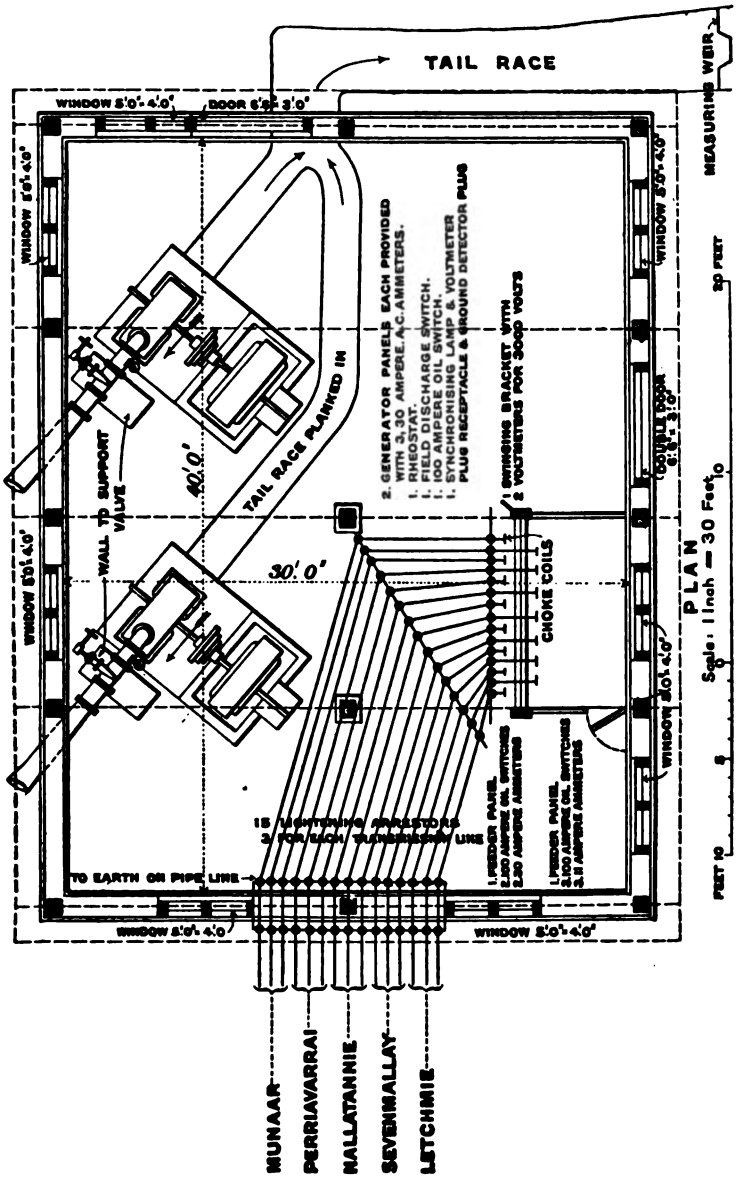

Fig. 5.

2½ per cent. increase when 25 per cent. of the load is thrown off,

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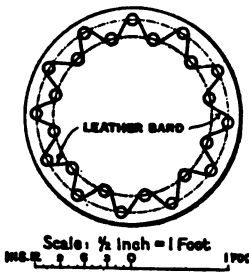
and 5 per cent. increase when 50 per cent. of the load is thrown off. With small changes of load these governors may be considered to comply with the specification, but they cannot be depended upon to deal with larger changes of load than 50 per cent. without an attendant to regulate the rheostats. The Author doubts whether there is a hydraulic governor on the market that will deal with sudden load changes of over 50 per cent. with a speed variation of only 5 per cent.

The turbines are fitted with pressure gauges and speed indicators. Each supply-pipe is fitted with a sluice valve worked by a hand-wheel and worm gearing placed inside the power-house. Automatic relief valves are provided on the service-pipe to diminish shocks when the turbine nozzle is closed suddenly, and these valves can be adjusted to open quickly and close slowly. The turbines are started and stopped by means of small handles acting on the governor, and the speed can be varied to the extent of 10 per cent., while the machines are running, by means of a screw adjustment. The turbines are capable of driving the generators at 500 revolutions per minute when the latter are delivering their full output of 100 kilowatts, although they were originally intended to drive 75-kilowatt machines.

The electrical plant at the power-station (*Fig. 5*) consists of two three-phase alternating current generators of 100 kilowatts capacity each, with continuous current exciters mounted on the generator shafts. Each generator is directly connected to its turbine by means of a flexible coupling of the type shown in *Fig. 6*. The generators are of the revolving-field type and are designed to develop current at 2,200 volts when running at 500 revolutions per minute. They are three-phase with a frequency of 50 cycles per second, and then the output is 26 amperes per terminal. The revolving magnets are provided with twelve poles. Each exciter has an output of 3·75 kilowatts (i.e. 30 amperes at 125 volts continuous current). The generators were specified to develop their full rated output continuously with a temperature rise not exceeding 40° C. above that of the surrounding air, and to carry 10 per cent. overload continuously with a temperature rise not exceeding 50° C. The switchboard in the power-station consists of two generator panels of white marble, each fitted with 3 ammeters reading up to 30 amperes, and with

Fig. 6.



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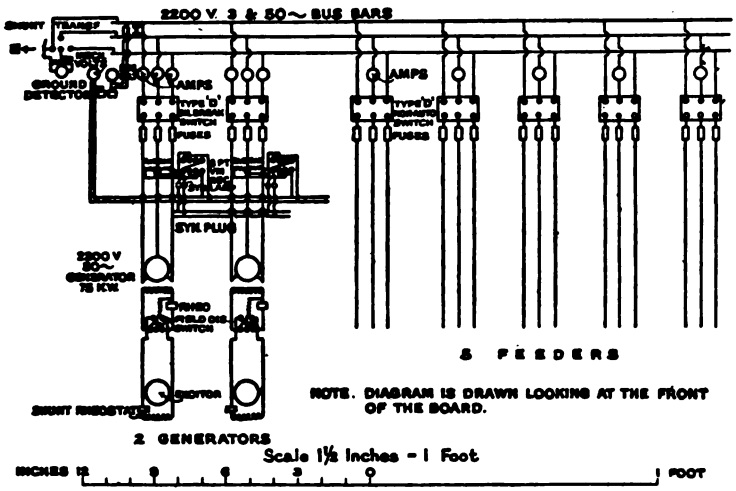
exciter and field rheostat, exciter switch and three-pole oil-switches for the connection between generators and bus-bars, synchronising lamps and plugs and "earth" detector lamp. Fuses are provided at the back of the board between the generators and bus-bars. There are two panels for the feeder circuits fitted with five three-pole oil-switches and five ammeters, and fuses are placed at the back of the board for each circuit. Two voltmeters are fixed to swinging brackets at the end of the switch-board; one is for the machines and the other for the bus-bars. A diagram of the connections is given in *Fig. 7*.

The shunt transformers for lighting, etc., the main and the synchronising bus-bars, the rheostats and the primary fuses are all

Fig. 7.



fixed on the back of the switch-board, which is partitioned off from the power-station; thus there is nothing exposed on the front of the board which might cause injury to the operators. The connection between the switch-board and transmission-lines is made with insulated cable (5,000 megohm grade) carried overhead to the terminals of the transmission-line just outside the power-house. The switch-board is protected by five sets of Wurts lightning-arresters and choking-coils. The lightning-arresters are earthed outside the station to the turbine service-pipes. These arresters are not quite as effective as might be wished, and on two occasions, in heavy thunderstorms, lightning has passed the choking-coils and has caused damage to the switch-board fittings. In consequence,

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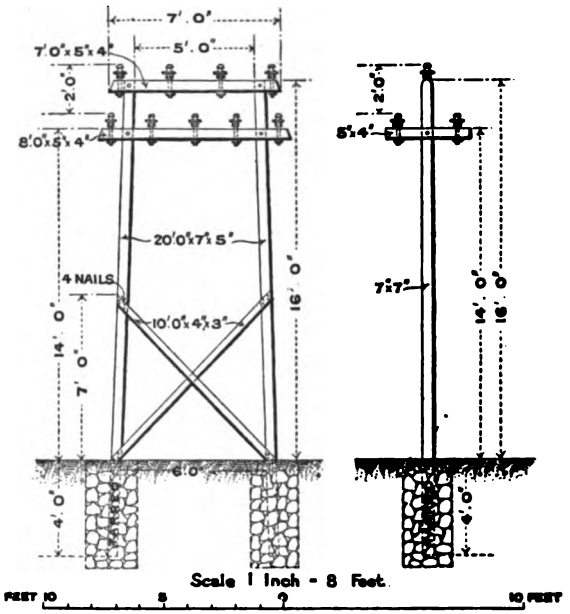
the Author has recommended that horn arresters should be provided on the line as additional protection.

The power-house is 40 feet by 30 feet, is built of timber with weather-boarded walls, and is roofed with corrugated-iron sheets. The floor is of rough stone plastered with cement mortar. There is a wooden platform in front of the switch-board under which the insulated cables are led from the generators to the back of the switch-board. A small bungalow was built near the power-house for the engineer-in-charge, and also houses for the operators and coolies employed. The total cost of these buildings was £251 8*s.* 6*d.*

Figs. 8.



Transmission-Line.—All the wires for the five circuits are carried from the power-house across the river on double posts. From this point the three sets of wires for the Munaar, Nallatanni and Periavurray factories are carried to the Munaar factory, a distance of 2 miles, on double posts, as shown in *Figs. 8.* From the Munaar factory the Nallatanni and Periavurray wires are carried on single posts fitted with two cross arms for a distance of about half a mile, when the two lines separate and are carried on single posts (*Figs. 8*) to their respective factories. The Letchmie and

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Sevenmallay lines are carried on single posts from the points where they diverge from the main line near the river at the power-house. The posts and cross arms are of timber sawn in the adjacent jungles. The lower 6 feet of the posts was tarred, sunk 4 feet into the ground and built in with rough stones. No special precautions were taken to protect the posts from white ants, as they do not infest the district.

Porcelain insulators of the double petticoated type were used throughout, and they are fixed to the cross arms as indicated in *Figs. 8*. These insulators were specified to maintain a good insulation under the heaviest rainfall experienced in the district, and when tested with 500 volts, the insulation resistance was found to range from 2 megohms per mile in the middle of the monsoon to 30 megohms per mile in comparatively fine weather.

The size of wire used is the same for all the circuits, and it is no larger than is necessary to ensure mechanical strength. It consists of bare hard-drawn copper wire 0·137 inch diameter (i.e. between Nos. 9 and 10 B.S.G.), and weighs 300 lbs. per mile, and was specified to be of the highest conductivity. The cross-sectional area of each conductor is 0·0147 square inch; the maximum current density is therefore about 1,000 amperes per square inch. The actual resistance of 4 miles of conductor was found to be 11·5 ohms or 2·88 ohms per mile; hence the voltage drop with maximum current (15 amperes) on the Munaar line is 86 volts, and it is 151 volts on the Letchmie line. The actual voltage at the factories is therefore somewhat greater than originally calculated. The aggregate length of all the lines is 15 miles, but on account of the rough nature of the country traversed it was considered advisable to allow 10 per cent. extra, so that 50 miles of wire were supplied, and this amount has proved ample. The posts are fixed between 40 and 50 yards apart, and the lowest wire was fixed 14 feet above the ground at the supports, and as far as possible this minimum distance of 14 feet is maintained throughout the spans.

Factory Motors and Fittings.—A diagram of the connections for the factory motors is given in *Fig. 9*. The current is transformed down to 200 volts at each of the factories by three single-phase transformers connected in mesh. These transformers are of the oil-cooled type, and the secondaries are tapped at an intermediate point so as to give the reduced voltage of 134 volts, together with an increased current, in order to facilitate the starting of the induction motors. Each of the transformers for the 20-HP. motors has a capacity of 7½ kilowatts, and those for the 50-HP. motors

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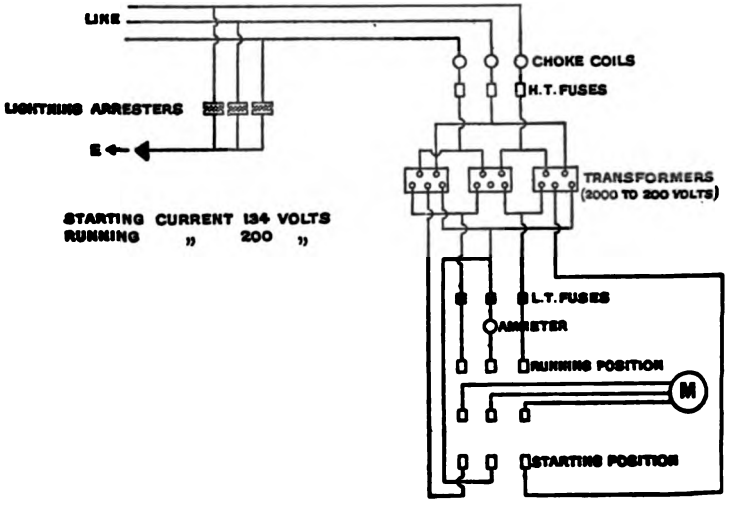
have a capacity of 20 kilowatts. This leaves an ample margin for lighting the factories. The motors are of the squirrel-cage three-phase induction type wound for 200 volts. Every motor is supplied with a small marble switch panel on which is fitted one ammeter, the primary fuses and one three-pole change-over starting switch. The secondary fuses for the protection of the motors are mounted on the rear of the switch-panels. The switch-boards in the factories are protected by lightning-arresters of the same type as those in the power-house. The speed specified for the 20-HP. motors was 940 revolutions per minute, and for the 50-HP. motors 720 revolutions per minute, but owing to the voltage drop on the line being

Fig. 9.



less than that calculated, the motors run slightly above their specified speeds. The pulleys of the 20-HP. motors are 11 inches in diameter, and those of the 50-HP. motors are 15 inches in diameter. These sizes are smaller than the standard pulleys supplied by the makers of the motors, but were specified because it was desired to drive the main shafting direct at 150 revolutions per minute without unduly increasing the size of the main-shafting pulleys. No difficulty has been experienced so far with these smaller pulleys.

As already stated, the power-house, together with the transmission-lines and the motors, etc., for four of the factories were completed at the beginning of May, 1906. The spring of that year happened to be exceptionally dry, and consequently the water-supply in

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the district was very low indeed; in fact, when the April and May showers set in, some of the streams that provide water-power to the factories failed altogether. It was therefore necessary, in order to save the May crop of tea, which was a heavy one, to put the new installation to work with practically no preliminary trial, no time being available for giving the machinery more than one day's run; and in some cases the motors were put to work within a few hours of the last connections being joined up. These motors were run day and night without a stop for over 4 weeks. By the middle of June the monsoon had set in and the water-supply in the streams increased; consequently the factories ceased to require so much assistance from the electrical power plant, and it became possible to shut down the plant for one day per week and partially to discontinue all-night working. This was a great relief, as it enabled the machines to be cleaned and native operators to be trained.

The following is a schedule of the cost of the several works:—

	Rs.	A.	P.	£	s.	d.
Cost of electrical plant, including transmission wire and insulators (f.o.b.)	38,339	11	0	2,555	19	7
Cost of hydraulic plant (f.o.b.)	6,530	4	0	435	7	0
„ service-pipes (f.o.b.)	8,366	0	0	557	14	8
Erection of electrical plant in power-house	649	1	6	43	5	6
„ hydraulic „ „ „	476	14	2	31	15	10
„ service-pipes, including masonry, etc.	2,517	2	0	167	16	2
Cost of power-house, bungalow, etc.	3,771	6	6	251	8	6
Erection of motors, etc., in factories, pulleys, etc.	2,076	2	11	138	8	3
Cost of water-channel, including intake and head-tank	7,201	15	10	480	2	3
Erection of transmission-line, including cost of posts, clearing jungle, etc.	6,474	13	1	431	13	1
Transport, freight, and duty	17,292	10	0	1,152	16	10
General charges, including two wire foot-bridges across the river, tools, and petty supervision	2,822	8	11	188	3	4
	Rs. 96,518	9	11	£6,434	11	0

It will be seen from these details of expenditure that the cost of freight, duty and transport was very heavy, amounting to nearly 18 per cent. of the total cost of the installation. The cost of transport was much enhanced by the exceptional difficulties encountered in moving the heavier articles from the low country to the top of the hills. The heaviest pieces that had to be dealt with were the generators, consisting of four pieces of 1½ ton each, and they had to be dragged up on rough trolleys by coolies from the foot of the hills, as the bridle path was too steep and narrow to permit the use of draught cattle. This path is about 7 miles long and rises 4,000 feet

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from the foot of the hills to the top, and it was a slow and troublesome business to transport these heavy and bulky articles over it. Great care had to be exercised, as the path is both narrow and crooked. The cost of transporting these four pieces alone exceeded Rs.6,000 (i.e. £400). Mr. Blair Hill, the Company's transport manager, was responsible for this portion of the work, and great credit is due to him for the expeditious way in which it was carried out. No trouble was experienced from the top of the hills to Munaar (22 miles), as all the goods were transported by the Company's tramway. From Munaar to the power-house (5 miles), however, there was some difficult country to contend with, and over the last 2 miles the heavy articles had to be drawn on rollers down a steep and crooked riding path, and temporary wooden bridges had to be erected to cross the rocky bed of the river.

The annual cost of running the installation, including maintenance and proportion of engineer's salary, is estimated at Rs.6,000 (£400). The actual amount of tea that will be manufactured by the power derived from the installation is 2,000,000 lbs. per annum; allowing 5 per cent. interest on capital and 5 per cent. for depreciation, the total cost of power for manufacture is about 0·13 of a penny per pound of tea. The installation will enable the factories to be lighted by electricity, which, in addition to giving better light, will effect an annual saving of £66 13*s.* 3*d.*

The Author takes this opportunity of thanking Mr. G. W. Cole, the Company's mechanical engineer, for his share in the work, to which the success of the undertaking was largely due.

The Paper is accompanied by two tracings, from a selection of which the Figures in the text have been prepared.

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OBITUARY.

THOMAS BURRELL BEWICK, who died on the 5th February, 1907, aged 50, was a native of Northumberland. Born on the 5th December, 1856, he was the son of the late Mr. Thomas John Bewick, senior partner in the firm of Bewick, Moreing and Company, under whom he was trained for the engineering profession. He was assistant Manager of the Langley Barony Lead Mines and Smelting Works at Hepburn-on-Tyne, from 1879 to 1890, when he became Managing Director of the company. In 1890 he succeeded his father as a partner in the firm of Bewick, Moreing and Company, mining engineers and mine managers, and from that date until his retirement in 1901, he took an active share in the direction of the firm's extensive business at home and in the colonies.

Mr. Bewick was elected an Associate Member of The Institution on the 7th February, 1882, and was transferred to the class of Members on the 22nd December, 1896.

JOHN RICHARD BRITTLE was born on the 11th May, 1845. He gained a Whitworth Scholarship and matriculated in the Applied Science Department of King's College, London, in 1869, and on completing his college course he became a lecturer on engineering construction and surveying at the Hartley Institute, Southampton. In July, 1873, he entered the cable department of Messrs. Siemens Brothers, where he remained until his death. At first he acted as an assistant to the late Mr. Carl Siemens and the late Mr. Ludwig Loeffler, but in November, 1875, he was placed in charge of a cable-repairing expedition, and thenceforward he became responsible for most of the cable-laying work carried out by the firm. For a time he also had charge of the electric lighting department, and in January, 1878, in conjunction with Dr. Paget Higgs, he read a Paper on "Some Recent Improvements in Dynamo-Electric Apparatus"[1] before The Institution, for which the Authors were

[1] Minutes of Proceedings Inst. C.E., vol. lii, p. 36.

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awarded Telford Medals and premiums. Having to spend much of his time on board ship he took up the study of navigation, of which he acquired sufficient knowledge to obtain a first-mate's certificate. His sound theoretical attainments and extensive practical experience rendered his services of great value to the firm, whilst his success in surmounting difficulties and the conscientious manner in which he carried out all his work inspired general confidence in his ability. He died at Blackheath on the 25th February, 1907.

Mr. Brittle was elected an Associate of The Institution on the 5th May, 1874, was subsequently placed in the class of Associate Members and was transferred to the class of Members on the 1st March, 1886.

ROBERT CHAPMAN, second son of the Reverend S. T. Chapman, was born at Kingston-on-Thames on the 16th January, 1821, and received a private education. In 1840 he was placed under the late Sir John Coode, Past-President, with whom he served on the Great Western Railway at Paddington, Swindon, Bristol and other places for a period of 3 years. He was next employed on the construction of the Bristol and Exeter Railway, and subsequently he succeeded Sir John (then Mr.) Coode on the South Devon Railway at Plymouth. Whilst there he superintended the erection of five large viaducts in the neighbourhood of Ivybridge, and built also a floating pier for the Great Western Dock Company. In 1853 he was appointed by the late Mr. Brunel assistant engineer at Paddington, where at that time extensive works were in progress, amongst which the removal of some heavy brick bridges over the main line came under Mr. Chapman's supervision. In the following year he was selected for the appointment of Resident Engineer at Leamington, where he remained for 13 years. In 1867, at the desire of the late Sir Daniel Gooch, then Chairman of the company, Mr. Chapman took charge as Resident Engineer of the Shrewsbury and Chester district of the Great Western system, including branch lines in North Wales and work at Liverpool and Birkenhead, and this appointment he held until his retirement from the company's service in 1896, a period of 28 years. He died at Bournemouth on the 17th October, 1906, in his eighty-sixth year.

Mr. Chapman was elected a Member of The Institution on the 12th January, 1864.

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HUGH MORTIMER HERBERT COLLIER, born on the 23rd September, 1864, was educated privately and at Eton College. After serving a pupilage to the late Mr. George Fosbery Lyster, Engineer to the Mersey Dock Estate, he was appointed an assistant on the dockyard staff, and was engaged on construction and improvement works at the New South Docks. In 1892 he entered the service of the London and India Docks Joint Committee and was appointed Resident Engineer in charge of the East and West India Docks, under Mr. H. F. Donaldson, then Chief Engineer. Besides being responsible for the general maintenance and dredging of these docks, Mr. Collier was charged with the construction of the new Blackwall entrance, import and export dock entrances, a pumping station, and a series of large timber sheds, and carried out the lengthening of several swing railway bridges. He resigned his appointment in December, 1894, on account of ill-health. In 1897 he accepted a position on the staff of Sir John Wolfe Barry, Past-President, for whom he acted as Resident Engineer at Limehouse dock, on the reconstruction of Lady Windsor lock, Barry, and at Middlesbrough dock. He was engaged on the latter work when his health finally gave way 9 months before his death, which occurred on the 14th June, 1906.

Mr. Collier was elected an Associate Member of The Institution on the 10th January, 1893, and was transferred to the class of Members on the 13th December, 1904.

JOHN ELLIOTT was born at Long Benton, near Newcastle-on-Tyne, on the 15th March, 1822. He was first employed in the West Moor Colliery at Killingworth, as an engine-wright and driver, and left during the miners' strike in 1842 to become an engine driver on the Brandling Junction Railway at Gateshead, where he remained about 2 years. In 1844 he entered the service of Messrs. Robert Stephenson and Company, of Newcastle-on-Tyne, and 12 months later he was sent to Florence to superintend the erection of twelve locomotives for the Florence and Pisa Railway, and to take charge of running during the term of their guarantee. At the expiration of that period he transferred his services to the railway company in the capacity of Locomotive Superintendent.

In 1856 he obtained the post of chief mechanic to the Leopoldina Railways at Florence, which he relinquished in 1863 for that of Locomotive Superintendent of the Livornesi and Roman Rail-

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ways at Leghorn, where he remained until 1874, when he was transferred to Foligno. During the latter period he was also connected with the improvements of the harbour of Leghorn, and the construction of the breakwater. In 1877, for his work in connection with railway development, Mr. Elliott was made Cavalier of the Order of the Crown of Italy by the late King Victor Emanuel II. From Foligno he went to Florence in 1880, and 3 years later, on reaching the age limit of service, he retired on pension.

In 1884 he acted as Chief Mechanical Engineer for the contractors of the Florence-Faenza Railway, and designed all the machinery in connection with the driving of the Cercina Tunnel. Subsequently he was appointed Chief Government Inspector of Boilers for the Province of Tuscany, and retained this office up to the time of his death. He died on the 9th December, 1906, after a brief illness, at his residence in Florence.

Mr. Elliott was elected a Member of The Institution on the 6th February, 1872.

JAMES THOMAS FORD was born on the 21st January, 1862, in Jamaica, and commenced his engineering career in the Public Works Department of that colony in 1877. He remained in the public service until 1886, when he went to Cuba to carry out a scheme of irrigation for a large sugar plantation. In the following year he obtained employment with the Nicaragua Canal Construction Company, and took part as Chief Assistant Engineer in the expedition for the final location of the work. On the return of the expedition, Mr. Ford's services were retained to assist in the preparation of plans and estimates, and he was subsequently deputed to represent the company in Paris, returning to New York in 1890 to fill the position of Manager. After practising for a short time as a Consulting Engineer in New York, he accepted an engagement with the Cartagena-Magdalena Railway Company, for whom he carried out surveys and reported on the proposed railway, wharves and other works in Colombia, which were then constructed under his direction. In 1894 he was appointed Chief Engineer to the company, and 2 years later he added to this appointment the office of General Manager. In 1906 the property was transferred to an English company, of which Mr. Ford became Managing Director, and held charge of the railway and steamer fleet as well as of other enterprises owned by the company in the interior. In recent years, he became interested in the Panama Canal project, and was

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appointed to represent the Columbian Government on the International Commission. In 1901 he read a Paper before The Institution on "The Present Condition and Prospects of the Panama Canal Works,"[1] for which he was awarded a Telford premium. Whilst engaged in extensive operations in the interior of Colombia in 1906, he received a sunstroke, which eventually resulted in his untimely death on the 3rd May, 1907, at the age of 45.

Mr. Ford was elected an Associate Member of The Institution on the 2nd April, 1889, and was transferred to the class of Members on the 28th March, 1899.

EMMANUEL LEWIS GALIZIA, Superintendent of Public Works to the Maltese Government, died at Malta on the 6th May, 1906, aged 76. Born in 1830, he was educated at the Malta University, and after serving several years in the Land Revenue and Public Works Department, he received a warrant to practise the profession of Surveyor and Architect in 1852. He was appointed Assistant Surveyor and Valuer of Government land property in 1854, and 2 years later he was promoted Surveyor. In 1860 he became Chief Government Surveyor, in which capacity he had the entire direction of the Public Works branch, and was responsible during the succeeding 20 years for the execution of works amounting in the aggregate to nearly £700,000. In June, 1880, the Public Works service was made an independent department, and Mr. Galizia received the appointment of Superintendent of Public Works, having sole charge of all public works, roads and buildings throughout the island where, in the absence of municipalities, all institutions of a public nature are provided and maintained by Government. Mr. Galizia was also responsible for the maintenance of Crown property covering nearly one-third of the area of the Colony.

A complete survey and a set of records and descriptive plans of all Government property in Malta and Gozo were made under his direction, and after the British occupation of Cyprus in 1877, he was entrusted by the Imperial Government with two special missions to report on that island generally, and on behalf of the Government of Malta he inspected certain parts of it with a view to the establishment of a Maltese settlement. He also represented the local government in connection with the extension, for commercial pur-

[1] Minutes of Proceedings Inst. C.E., vol. cxliv, p. 150.

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poses, of the upper part of the Grand Harbour, carried out by the Admiralty for the purpose of freeing the lower and deep waters for naval purposes. During his tenure of office, the Public Works Department was completely reorganized and raised to a high level of efficiency. He retired in 1888, after 42 years' service.

As Superintendent of Public Works, he occupied a seat in the Legislative Council of the Colony. He was also a member of the Drainage Commission and Consulting Engineer to the Medical Board. Many public buildings scattered throughout Malta and Gozo testify to his architectural ability, which was recognized by his election as a Fellow of the Royal Institute of British Architects. His tact and affability endeared him to the whole community, whilst the ability and thoroughness which he displayed in all his work gives him a permanent place in the record of professional achievement in Malta.

Mr. Galizia was elected a Member of The Institution on the 12th January, 1886.

EUGENE GRIFFIN was born at Ellsworth in the State of Maine, on the 13th October, 1855. He graduated from the United States Military Academy at West Point in 1875, with high honours, and was appointed second lieutenant of Engineers in the United States Army. After being employed for several years on the United States Geographical Survey, he was promoted to first lieutenant in 1880, and was placed in charge of surveys of Governor's, Ellis, and Bedloe's Islands, in New York harbour. From 1883 to 1885 he was Assistant Professor of Civil and Military Engineering and the Art of War at West Point, and subsequently he acted as Assistant Engineer Commissioner of the District of Columbia, having charge of all matters relating to electric lighting, telegraph and telephone services in the City of Washington. In 1887 he was promoted to the rank of captain in the Corps of Engineers.

A report which he made on the possibilities of electric railways and electric lighting in the City of Washington brought him into contact with the Thomson-Houston Company, and early in 1888 he accepted the invitation of the company to organize and take over the management of its Railway Department. The application of electricity to street railways in America was then in its infancy, but Captain Griffin had full confidence in its future development, the magnitude of which he clearly foresaw. The first electric railway equipped by the company was opened at Revere Beach, near Boston,

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in July, 1888, and a number of other installations followed in rapid succession.

Captain Griffin took a prominent part, and displayed great ability and business acumen, in the reorganization and amalgamation of the Thomson-Houston and Edison General Electric Companies, which took place in 1892, and on the formation of the new company, under the style of the General Electric Company, he was appointed Director and first Vice-President, and retained these offices until his death.

On the outbreak of war with Spain in 1898 he offered his services to his country, and was commissioned to organize the First Regiment of Volunteer Engineers, which he commanded until the close of hostilities. He was promoted to the rank of Brigadier General prior to his regiment being mustered out of service, when he resumed his duties with the General Electric Company.

Despite failing health in the closing years of his career, his zeal and interest in business never abated, and he was actively engaged up to the end. Both in public and private life General Griffin was the embodiment of honour and courtesy, whilst his versatile and manifold accomplishments contributed to a personality which attracted and impressed all who came under its influence. He maintained up to the last the liveliest interest in West Point, where he enjoyed a deserved popularity, and was a frequent visitor. He died on the 11th April, 1907, and was buried at West Point with full military honours.

He was elected a Member of The Institution on the 14th April, 1896.

GEORGE CECIL KENYON, born on the 3rd January, 1875, was the elder surviving son of Mr. T. R. Kenyon of Aughton, near Liverpool. After studying at the University and undergoing a preliminary training in mechanical workshops in Liverpool, he served his pupilage to Mr. Anthony G. Lyster, Engineer-in-Chief to the Mersey Dock Estate. On completing his articles in 1896 he joined the engineering staff of the Estate, remaining in their service until his untimely death on the 30th October, 1906, at the age of 31. During his brief engineering career, Mr. Kenyon carried out a number of important works at Liverpool, under the direction of Mr. Lyster, and without the intervention of contractors, including the extension of the Leasowe sea embankment; the alteration of the

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sills of Langton Dock Entrances; the widening and deepening of the east passage between Langton and Alexandra Docks; afterwards taking up the work of the main sections of the remodelling of the southern Liverpool Docks, including the construction of deep water entrances to Brunswick Dock 100 feet and 80 feet wide respectively; the deepening of the Brunswick Dock, 13 acres in extent, and the underpinning of its old walls; and the construction of two new docks, each about 1,000 feet long, on the site of the old Wapping and King's Docks, with all the necessary shed, railway and other accommodation. Throughout the course of these works, in which he was responsible for a total expenditure of over a million sterling, Mr. Kenyon displayed great capacity and energy, and shortly before his death he was promoted to the position of an Assistant to the Engineer-in-Chief with duties of a more general character.

Mr. Kenyon was a Member of the Institution of Mechanical Engineers, and of the American Society of Civil Engineers, and was the author of several valuable communications upon subjects comprised in the branch of engineering with which he was concerned. He was formerly a lieutenant in the Engineers (Volunteers), and afterwards held a like rank in the 4th Rifles, but was obliged to resign his commission owing to stress of work.

Mr. Kenyon was elected a Member of The Institution on the 7th March, 1905

HUGH UNSWORTH McKIE died at Spondon, Derbyshire, on the 19th January, 1907, at the advanced age of 84. He had retired in 1898 from a professional career exceptionally full and varied, which he had pursued with unflagging energy and marked ability for a period of nearly 60 years. Born at Garstang, near Lancaster, on the 16th May, 1822, he served his pupilage to Mr. William Lamb, a land surveyor and agent to the Duke of Hamilton. Between 1844 and 1850 he engaged in private practice at Lancaster in partnership with Mr. John Lawson, and carried out sewerage and waterworks for Lancaster and other places. During this period, Mr. McKie also acted as Resident Engineer on part of the North Western railway and harbour works at Morecambe. From 1850 to 1856 he was engaged under the late Sir Robert (then Mr.) Rawlinson, Past-President, on water-supply and sewerage works at Alnwick, Carlisle and North Shields, in the course of which he introduced

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several improvements in the design and method of laying sewers. In 1856 he was appointed City Engineer and Surveyor of Carlisle, and held the appointment until 1860, at the same time carrying on private practice in partnership with his former pupil, the late Mr. James Mansergh, Past-President. Whilst at Carlisle, he designed and carried out, in addition to street improvements and other works, a sewage irrigation farm for the city and sewerage works for Rothbury and Silloth. From 1860 to 1865 he was occupied in the preparation of parliamentary and working drawings for the Conway and Llanrwst Railway, subsequently acting as Contractor's Engineer on its construction; and later he superintended, in the same capacity, the setting out of a railway line and tramways in the south of France.

Between 1867 and 1876, in the North Wales district, where he had established a consulting practice, he was responsible for the extension of the harbour at Portmadoc, sewerage works for Portmadoc and other towns, and, jointly with the late Mr. Thomas Duncan, waterworks at Rhyl, St. Asaph and Abergele. He was also concerned with Mr. C. E. Spooner in the location and construction of the North Wales narrow-gauge railways. During this period, also, he acted as Engineer for large Welsh slate quarries, and reported on other slate quarries at home and abroad. He likewise prepared plans for the Alexandra Palace Railway, and for the Berlin West-end waterworks, and acted as Resident Engineer on the main sewerage works of Southport.

In 1877 Mr. McKie was a second time appointed to the office of City Engineer and Surveyor of Carlisle, and retaining the appointment until 1889 he carried out a number of street improvements, designed and erected public slaughter-houses and other municipal buildings, laid out a public park and new cemeteries, and prepared a report and plans for the disposal of the sewage of the city. At the same time carrying on private practice outside the city boundaries, he was responsible for sewerage and waterworks at Netherby, Haltwhistle, Wetheral and Maryport, and flood-protection works on the River Nith above Dumfries.

Leaving Carlisle in 1889, Mr. McKie established a consulting practice in Westminster, and carried out water-supply works for Frimley and Farnborough, and was consulted on numerous other water and sewerage schemes. He retired from professional pursuits in 1898, at the age of 76, and during the remaining years of his life enjoyed a well-earned rest, continuing, however, up to the last to take an intelligent interest in everything affecting engineering science.

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Mr. McKie was elected an Associate of The Institution on the 1st March 1859, was subsequently placed in the class of Associate Members, and was transferred to the class of Members on the 1st December, 1885.

JOSEPH NEWEY died on the 9th January, 1907, at his home, near Kei Road Station in the Eastern Province of the Cape Colony. He was born on the 15th December, 1846, at Dudley, Worcestershire, and gained considerable experience under his father of railway and bridge work in England and on the Continent. In 1872 he was appointed Engineer on the staff of the Chief Inspector of Public Works of the Cape Colony. His first work in South Africa was the erection of the Buffalo, Committee's and Great Kei Bridges and the reconstruction of all the Eastern Province bridges destroyed by floods in 1874. During the construction of the Great Kei Bridge the Gaika Rebellion broke out, and Mr. Newey exhibited conspicuous courage in carrying out, at great personal risk, engineering work for facilitating army movements and defensive operations, during this and later campaigns. His intimate knowledge of the country and ready resource were of great benefit to the military authorities, and in the Gaika war he was placed in personal touch with General Gordon for the execution of military engineering works. Subsequently he was entrusted with the survey and construction of many main trunk lines of road in the Colony and Transkeian Territories, and during a series of years was in charge of the pioneer road and bridge work that has so greatly contributed to the development of the eastern portion of the country.

In 1881 he was appointed District Inspector of Public Works, having control of an extensive and important departmental area, in which, in addition to engineering works, he was entrusted with the selection and laying out of townships and the control of architectural and other works. Amongst the many bridges built under his direction may be mentioned the fine stone structures over the Kraai River at Aliwal North and Barkly East. In 1893 he was promoted to the position of Chief Inspector of Public Works (the title then given to the Chief Colonial Engineer for all except railway works), in which capacity he served until his retirement on pension, at the end of June, 1905. As Chief Inspector, Mr. Newey was in charge of all Government engineering and architectural projects (with the exception of railways) throughout the Cape Colony.

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The late South African War occurred during his term of office, and his wide experience was again found of great assistance to the military authorities. Mr. Newey was a Justice of the Peace for the Cape Colony, and a Fellow of the Imperial Institute.

He was elected an Associate Member of The Institution on the 6th May, 1879, and was transferred to the class of Members on the 9th November, 1891.

JACQUES AUGUSTIN NORMAND, who died at his residence at Havre, France, on the 11th December, 1906, was the head of the well-known shipbuilding firm of that name long established at Havre, and a prominent representative of naval architecture in France. Born in 1839, he succeeded to the direction of the establishment on the death of his father, Augustin Normand, in 1871, and from that time until his death he devoted himself with exceptional vigour and ability to works of design and construction and to scientific research. Uniting high scientific attainments with great mechanical skill, his labours in both spheres of activity were productive of valuable results. All the vessels turned out of the Normand establishment were characterized by scientific excellence of design, but Mr. Normand's reputation was chiefly won in connection with the design and construction of vessels of the torpedo flotilla. In this branch he was the acknowledged leader in France, and the establishment of new types was to a great extent entrusted to the Normand firm by the Ministry of Marine. Step by step progress was made, not merely in the attainment of higher speeds but in securing remarkable economy in coal-consumption, an economy obtained by close study of the design of details in the propelling apparatus and the skilful prevention of waste of steam, as well as by the judicious introduction of new devices and apparatus, many of which originated in Mr. Normand's own fertile brain.

Throughout his career his pen was constantly employed, and notwithstanding his unremitting application to business, he found time to contribute to scientific and technical publications a number of valuable memoirs, among the last of which was his Paper "On the Propulsive Power of Screws necessary to avoid Cavitation,"[1] presented to The Institution in 1906. He was a Member of the Académie des Sciences, of the Société des Ingénieurs Civils de France, and of the Association Technique Maritime. A man of

[1] Minutes of Proceedings Inst. C.E., vol. clxv, p. 293.

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large views, Mr. Normand was no believer in professional secrecy, but was always ready to explain and defend the departures which he made. His death was widely regretted by his many friends, not only in France but in this country, as a great loss to the profession of which he was for so long a distinguished member.

Mr. Normand was elected a Member of The Institution on the 6th December, 1904.

JAMES PERRY, born at Garvagh, County Londonderry, on the 7th September, 1845, was educated at the local national school, and afterwards pursued his studies at Queen's College, Belfast, and the Royal College of Science, Dublin, graduating in engineering with first-class honours in Queen's University in 1873. He obtained his practical training in the shops of the Belfast and County Down Railway, and was subsequently employed on water-supply works at Beyrout, Syria, and in Belfast.

In 1877 he obtained the appointment of County Surveyor of Roscommon, and 5 years later he was transferred to Galway, where he held the office of County Surveyor until his death. In this capacity he was responsible for the maintenance and repair of over 1,000 miles of public roads, and for the design and execution of numerous bridges, buildings, coast-defence and other works for the national and local authorities. In addition to his official duties, Mr. Perry carried on an extensive private practice and acted as Consulting Engineer for large government relief works and on other work for the Congested Districts Board. He also carried out, amongst other undertakings, waterworks at Clifden and Bundoran, and large school buildings for the Rose Convent, Galway.

In 1888, in conjunction with his brother, Professor John Perry, and another, he built and equipped an electric station at Galway, from which power was supplied to private consumers. In the following year the partners obtained the Galway electric lighting order and proceeded to extend their works and put down additional machinery. The Galway Electric Company, Limited, was formed in 1897, and Mr. James Perry, as Managing Director and Chief Engineer, was responsible for the supervision of the business, which, under his management, increased considerably, necessitating further extension of the works and machinery. In 1905 the Company successfully undertook the public lighting of the town of Galway. The last important work which Mr. Perry undertook was the execution of a new waterworks scheme for Galway. He died, after

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a brief illness, at his residence, Wellpark, Galway, on the 28th November, 1906, aged 61, widely and deeply regretted.

Mr. Perry was elected a Member of The Institution on the 6th December, 1892.

WILLIAM FURNISS POTTER, born in Leeds on the 30th March, 1843, was educated at the Leeds Grammar School, under Dr. Barry, and served a pupilage of 4 years to the late Mr. John Fraser, of Leeds, subsequently acting as his assistant for a short time. Between 1865 and 1868 he was employed on the West Cheshire lines under the late Mr. J. S. Wilkinson. Mr. Potter then obtained an appointment on the engineering staff of the Madras Railway, and proceeding to India in 1869, he was engaged at first on the construction of 10 miles of the North West line: then on the maintenance of the second division of the North West line, and lastly, in charge of the first division of the South West line, 132 miles in length. He then went to Japan, and for 3 years, from 1874 to 1877, he was in the service of the Imperial Government Railways as Resident Engineer in charge of the surveys, plans, sections and estimates of 52 miles of new line, and of the construction of another section, as well as of the maintenance of open line. Returning to England in 1877, Mr. Potter engaged in private practice in Westminster until 1879, when he retired from professional pursuits. In 1879 he married Kate, daughter of Mr. W. Woods Mitchell, of Arundel, Sussex. He died at his residence, Arundel Lodge, Ilkley, on the 2nd May, 1907, aged 64.

Mr. Potter was elected a Member of The Institution on the 4th December, 1877, and in the following year he communicated a Paper entitled, "Railway Work in Japan,"[1] which was read and discussed at a meeting.

EDWARD PURSER, late General Manager and Chief Engineer of the Ottoman Railway, died at Smyrna on the 26th October, 1906, in his eighty-fifth year. The fifth son of the late Mr. John Purser, of Rathmines Castle, county Dublin, he was born on the 16th December, 1821, near Dublin, in which city he received his education, graduating in Arts at Dublin University in 1842. He

[1] Minutes of Proceedings Inst. C.E., vol. lvi, p. 2.

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served a pupilage under the late Sir William Cubitt, Past-President, subsequently acted as Resident Engineer on the floating landing stages at Liverpool, and was next employed for 3 years as principal assistant engineer on the construction of the metropolitan division of the Great Northern Railway.

In 1850 Mr. Purser joined the staff of the East Indian Railway, then about to be begun. Proceeding to India he served for 4 years in Bengal as chief assistant engineer under the late Mr. George Turnbull, and was then appointed Chief Engineer of the North West Provinces division of the line. The works in the North West included several fine ashlar arched bridges in the Mirzapur district, and large bridges over the Tonse river and the Jumna at Allahabad and Agra. All work was suspended at the outbreak of the Indian Mutiny, but Mr. Purser and his assistants remained at their posts and rendered assistance to the military officers in the construction of redoubts and other defence works.

In 1858 he resigned his appointment on the East Indian Railway, and in the following year, on the invitation of Sir Macdonald Stephenson, he went out to inspect the works of the Ottoman Railway, and shortly afterwards he was appointed Chief Engineer of the line. The construction of the line included heavy works in the Ephesus Pass, but these were successfully carried out, and the railway opened to Aidin in 1866. In the early stages of their enterprise, owing to the attitude of the Turkish Government and to other causes, the company experienced considerable financial difficulty, and during this period Mr. Purser rendered material assistance to the directors. Amongst other measures he urged the construction of various extensions of the line, and in 1868 he was appointed General Manager in addition to his office of Chief Engineer, and was entrusted with the conduct of negotiations with the Turkish Government to obtain concessions for the extensions which he advocated. These were subsequently constructed under his direction and resulted in a great improvement in the value of the undertaking. Mr. Purser had much at heart the further prolongation of the railway, and with that object in view extensive surveys were made in the country beyond Dinair, and he personally carried out a reconnaissance as far as Karaman in the hot months of 1899. In the following year he resigned his position, after 40 years' service with the company, at the age of 79, but continued to live at Smyrna until his death 6 years later. His career afforded ample proof of the professional skill and administrative capacity with which he was endowed, as well as of his courage and perseverance in the face of difficulty, but the popularity and

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esteem which he won from all was due to the influence of his personal character and to his generous and considerate disposition.

Mr. Purser was elected a Member of The Institution on the 7th February, 1860.

ARTHUR HENRY WHIPHAM, born at Chiswick on the 30th April, 1843, was the younger son of the late Mr. Thomas Henry Whipham, of Lincoln's Inn Fields, Barrister-at-Law. Educated at East Sheen and at King's College, London, he spent one year with the late Mr. James Cudworth at the Ashford works of the South Eastern Railway, and served a pupilage of 3 years, from 1864 to 1867, to the late Mr. William Cudworth, of the North Eastern Railway, Darlington. Subsequently he joined the staff of the latter company as Resident Engineer on the dock extension works at Middlesbrough.

In 1874 he left the company's service to take up the appointment of Engineer to the Owners of the Middlesbrough Estate, and, 10 years later, he was appointed General Manager and Secretary to that body, in which capacity he had charge of their large estates at Middlesbrough and Saltburn, as well as of their timber yards and salt works, which latter were designed and built under his supervision. During his management of the estates he played no small part in the development in the town of Middlesbrough and of the coast resort of Saltburn-by-the-Sea. In 1899, owing to ill health, he resigned his position, and took up his residence at Leamington, where he died on the 11th March, 1907, in his sixty-fourth year.

Mr. Whipham was elected an Associate of The Institution on the 9th April, 1872, and was transferred to the class of Members on the 30th April, 1878.

JAMES YOUNG, son of the late Mr. James Young, of Ruthven, Forfarshire, was born on the 14th June, 1845, and received his education at Ruthven Parish School and at the High School, Dundee. He obtained his practical training under Mr. D. H. Halkett, of Alyth, and subsequently undertook a course of study at Glasgow University under Professor Rankine. In 1868 he entered the Public Works Department of India as an Assistant Engineer and received promotion in due course, being finally appointed Executive Engineer with headquarters at Jacobabad, Sind. His work in India was chiefly connected with the irrigation service in

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Sind and Guzerat, where he was employed on extensive and important works of maintenance and construction. He remained in the public service until his retirement in 1898, a period of 30 years. After his retirement, he returned to Scotland, lived quietly at Meigle for several years, afterwards removing to Bridge of Allan, where he died on the 28th June, 1906, aged 61.

Mr. Young was elected a Member of The Institution on the 4th May, 1886.

CHARLES BLACKWELL, born at Foxhangers, near Devizes, Wiltshire, on the 4th February, 1843, was the eldest son of the late Mr. Thomas Evans Blackwell, who went to Canada in 1857 and subsequently became first Vice-President and General Manager of the Grand Trunk Railway. The subject of this notice studied at the High School and at McGill College, Montreal, and obtained his practical experience in the service of the Grand Trunk Railway. From 1869 to 1876 he was engaged upon the location and construction of the Intercolonial Railway, and during part of this period he supervised the equipment and erection of the machinery in the principal repair shops at Moncton, New Brunswick. During 1876 and 1877 he was Resident Engineer in charge of the completion of 45 miles of the Quebec, Montreal, Ottawa, and Occidental Railway, and in the two following years he acted in the same capacity on the construction of the Quebec Central Railway. In 1879 he was appointed Mechanical Engineer to the Dominion Department of Railways and Canals, and was responsible for the design and construction of all rolling stock required for the Canadian Pacific Railway, as well as for the water service. On the completion of the line in 1881 and its transfer to the Canadian Pacific Railway Company, Mr. Blackwell went to Roanoke, Virginia, as Superintendent of Motive Power of the Norfolk and Western and the Shenandoah Valley Railroads. The workshops at Roanoke were built and equipped in accordance with the plans and specifications prepared by him. In 1885 he left Roanoke and took service for 3 years with the Union Pacific Railroad, acting for a time as Manager of the Montana Division. Subsequently he became Engineer of the machinery department to the Central of Georgia Railway and remained with that company at Savannah, Georgia, for 2 years, when the state of his health obliged him to return to the north. Between 1891 and 1897 he was engaged as Engineer to the Schoenberger Steel Company, with headquarters at Pittsburg, but in the latter year, he returned to the railroad service on

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receiving the appointment of Engineer to the receivers of the Wheeling and Lake Erie Railroad. He remained with the company after its reconstruction until 1903, when he was offered the position of special assistant to the Chief Engineer of the Wabash Railroad. During this period he investigated and reported on several railroad properties in the United States. Accurate, methodical and resourceful, his extensive and varied experience eminently fitted him to fill the responsible and confidential positions which he occupied during the latter part of his career; whilst in private life, his sterling personal qualities endeared him to many friends. He died at Cincinnati on the 29th December, 1906, in his sixty-fourth year.

Mr. Blackwell married, in 1878, Emily, only daughter of Mr. Edward B. Chandler, Barrister-at-law, of Moncton, New Brunswick, and grand-daughter of the Hon. Edward Barron Chandler, Commissioner of Railways and Governor of the Province of New Brunswick. Mr. Blackwell was a Member of the American Society of Civil Engineers and of the Master Car-Builders' Association.

He was elected an Associate of The Institution on the 14th April, 1874, and was subsequently placed in the class of Associate Members.

ALBERT JOHNSTONE CAMPBELL, born at Stoke on the 7th December, 1854, was the last surviving member of the ancient family of Campbells of Glen Saddel. After being educated at Rugby, he entered the Royal School of Mines, of which he gained the Associateship in 1876. The next 4 years were spent in studying practical mining and engineering in Cornwall and Spain. In 1880 he was appointed General Manager of the Trojes and Aujangeo Silver Mines and Smelting Company, Mexico, a position which he held for 3 years.

In 1883 Mr. Campbell joined Mr. H. V. Rudston Read in partnership as Consulting Engineers in London, with a branch establishment in Mexico, and whilst in that country he carried out many important engineering works, both for the Mexican Government and for private clients, the most notable undertaking with which he was connected being the construction of the Tequixquiac Tunnel for the drainage of the Valley of Mexico. This tunnel was originally designed to be nearly 10 miles long, but owing to water difficulties and the nature of the ground, it was decided during the course of its construction to open up more than 3 miles of it, leaving the total length of the tunnel, as eventually completed, about 6¼ miles. The construction of this tunnel involved many interesting problems, in the

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solution of which Mr. Campbell displayed great skill and resource. The entire work took about 8 years to complete, and at the date of completion was the longest tunnel in existence completely lined with brickwork and cement blocks. Mr. Campbell's achievement was officially recognized by the Government of Mexico, and subsequently his firm was awarded a Gold Medal by the Committee of the Chicago Exhibition in recognition of the magnitude and importance of the work and its successful execution.

At a later date Mr. Campbell was jointly responsible with his partner, Mr. Rudston Read, for the construction of the Mexican Southern Railway, commenced in 1889 and completed in 1892. This line was the first railway in Mexico to cross the Sierre Madre Range, being thence continued down the Pacific slope. The whole time originally allowed for the construction of the railway was 10 years, but subsequently for political reasons a large bonus was offered for its completion in 3 years. Within the latter period the work was completely carried out and handed over, with the line fully ballasted and all masonry, culverts, and bridges in position, the full bonus being thus earned by Mr. Campbell's firm. A section of this railway is probably one of the heaviest pieces of work in the country, 60 miles of line being constructed in an almost impassable cañon. In the construction of this portion, 150 miles of side-roads had to be made for carrying supplies to the workmen, of whom 8,000 were employed at one time.

In 1896 Mr. Campbell returned to England and carried on consulting practice in London. The zeal and energy which he devoted to his work in Mexico told ultimately upon his health, and the illness which led to his death was traceable to fevers contracted many years before in the Mexican swamps. He died on the 23rd March, 1907, aged 52.

Mr. Campbell was elected an Associate Member of The Institution on the 14th April, 1885.

WILLIAM RICHARD THOMAS COTTRELL, born on the 22nd August, 1873, was educated at Bristol, and subsequently pursued his studies at the Central Technical College, London. In 1893 he was apprenticed to Messrs. Easton, Anderson and Goolden, of Erith, with whom, on completing his articles, he remained until 1898, taking charge of their electrical testing department during the latter part of his service. After temporary employment under the London County Council, he became an Assistant Engineer

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in 1900 on the construction staff of the London United Tramways, afterwards becoming Chief Assistant Engineer. From June, 1903, until his health broke down in 1906, he filled a similar position on the staff of the Central London Railway. Having developed tuberculosis, he was sent for treatment to a sanatorium, and afterwards to Switzerland, where, after a temporary improvement, he died on the 4th February, 1907, in his thirty-fourth year.

Mr. Cottrell was elected an Associate Member of The Institution on the 4th March, 1902.

HENRY DENNIS, born at Bodmin, Cornwall, in 1825, commenced his engineering career in the office of the Borough Surveyor of Bodmin, Mr. Henry Coom. On completing his training he joined the engineering staff of the Cornwall Railway, which now forms part of the Great Western system, and subsequently he was employed in surveying the coast-line and taking soundings in Padstow harbour with a view to the construction of a breakwater. The construction of mineral railways in the south of Spain during 1856 and 1857 brought him into contact with the mining branch of the profession, to which his subsequent career was principally devoted. Returning to England in the following year he was entrusted by the mining firm of Messrs. John Taylor and Sons with the construction of railways for the Llangollen Slate and Slab Company's mines in Denbighshire. Having settled in the district, Mr. Dennis turned his attention to its mineral resources, and from that time forward he took a prominent part in the development of the Wrexham coalfield, as well as of lead mines and stone quarries in the neighbourhood. He became manager of the Bryn-yr-Owen Colliery, and afterwards managing director of the Wrexham and Acton collieries and the Ruabon Coal and Coke Company; director of the Minera Lead Mining Company, and chairman of the Westminster Brymbo Coal and Coke Company, the Snailbeach Lead Mining Company, and other undertakings. He also carried on a private practice, and, as engineer, was instrumental in obtaining parliamentary powers for supplying Ruabon and several other districts with water and gas. He built the Glyn Valley railways, the Wrexham District tramways, and the Snailbeach Railway. He owned and managed the Cefn freestone quarries, and was identified with various other undertakings in the district. He also acted as consulting mining engineer to several large estates in North Wales.

Mr. Dennis was for some time chairman of the North Wales

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Coalowners' Association and their Mutual Indemnity Company, and he also represented the Association on the Coal Trade Conciliation Board. In 1904 he served the office of President of the Mining Institute of Great Britain. The claims of business left him little leisure for public affairs, but he served for a time as an Alderman of the Denbigh County Council, and was also a Justice of the Peace for the county. Agriculture was his hobby, and he acquired a considerable reputation as a breeder of sheep. He was taken ill immediately after a journey by motor-car from his home, New Hall, Ruabon, to his Cornish residence at Bodmin, and died at the latter place on the 24th June, 1906, in his eighty-second year.

Mr. Dennis was elected an Associate Member of The Institution on the 31st May, 1881.

JOHN FOLEY, born on the 18th August, 1852, was educated privately, and subsequently attended lectures at King's College, London. He was trained in the office of the late Mr. Henry Law, with whom he served as an assistant for a period of about 9 years, 3 years of which were spent on the construction of drainage works for the City of Pernambuco, Brazil.

Between 1876 and 1879 he was engaged at Widnes on the design and construction of extensions to the waterworks, including a covered reservoir of 10,000,000 gallons capacity. In 1879 he went to Corsica as Manager of the Bastia Gasworks, and for 3 years subsequently he was employed in the engineering office of the New River Company under Mr. Joseph Francis, M. Inst. C.E., in designing pumping stations and other works. He was next engaged in the construction of gasworks in France and Italy for the European Gas Company and the Compagnie l'Union des Gaz, and subsequently he was employed for short periods on waterworks for the town of Longford, Ireland, on extensions to the drainage works at Rio, and in the preparation of contract drawings for the Abbey Mills Sewage Outfall Works and for the Geltsdale Water Scheme for the water-supply of Carlisle. On the completion of the last work he assisted Mr. Charles Butterworth, the engineer for the Carlisle scheme, in his private practice. He was last employed on the engineering staff of Mr. Imrie Kiralfy in connection with exhibition work. Mr. Foley died on the 2nd June, 1906, in his fifty-fourth year.

He was elected an Associate Member of The Institution on the 3rd December, 1901.

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WILLIAM HENRY HOLTTUM was born at Dover on the 1st February, 1851, and served an apprenticeship of 3 years to Messrs. Ordish and Le Feuvre, of Westminster. In 1872 he entered the office of Mr. W. Barns Kinsey, under whom, for a period of more than 12 years, he was engaged in the preparation of designs, specifications and estimates for waterworks and sewerage schemes, amongst others those at Pembroke, Petersfield, Limpsfield and Oxted, and for works of general building construction. As Mr. Kinsey's chief assistant, he was responsible for the surveys and levels and superintended the construction of these works. For 2 years he had charge of water-supply works and of the Thames Haven cattle landing-stage for Mr. A. L. Stride, Chief Engineer of the London, Tilbury and Southend Railway. Subsequently he superintended the sinking of a large artesian well in Aldgate, for the late Colonel Haywood, and prepared a specification and estimate, on his own designs, for the pumping and water service therefrom. He next acted as Engineering Manager to Messrs. Le Grand and Sutcliff, artesian-well borers and contractors, advising on water supplies and superintending the construction of wells in all parts of the country. For nearly 5 years he had charge, under Mr. A. Ross, of tunnelling works for the Great Northern Railway. He then obtained an appointment as Surveyor in the Engineer's Department of the London County Council, which he retained until his death. Besides surveys of sewerage outfall and other works, he designed in detail works of dock construction, river walls and street improvements. He died on the 11th July, 1907, aged 56.

Mr. Holttum was elected an Associate Member of The Institution on the 29th May, 1883.

CHARLES JOHNSTON, youngest son of Mr. J. W. Johnston, solicitor, of Stockport and Teddington, was born on the 23rd October, 1877. Educated at Reigate Grammar School, he served his pupilage to the late Mr. A. M. Fowler, by whom he was employed on the Stockport sewerage scheme and other works. Subsequently he was engaged under the Tiverton and Leicester Corporations, chiefly on sanitary work, and as an engineering assistant to Mr. J. W. Bradley, City Engineer of Westminster. In 1902 he obtained an appointment in the Indian Public Works Department, and proceeding to India in November of that year, he was posted to the Begari canals as an assistant engineer. His performance of the

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duties allotted to him was satisfactory in every respect, and on two occasions he was specially commended by the Indian Government for his promptitude and resource in dealing with flood-breaches in dams under his charge. The promise thus given of a successful professional career was destined, however, to remain unfulfilled. Whilst on a duck-shooting expedition in the neighbourhood of Jacobabad, he met an untimely death by drowning in the Sind Dhoro, on the 8th February, 1907. He was in his thirtieth year.

Mr. Johnston was elected an Associate Member of The Institution on the 13th January, 1903.

RICHARD HENRY MIDDLETON, born on the 8th April, 1856, served his apprenticeship to Mr. Richard Horsfall, Engineer and Surveyor, Halifax. In 1881 he was appointed Assistant Borough Engineer of Dewsbury, where he was engaged on extensive main drainage works, and 2 years later he was selected to fill a similar position at Birkenhead. In 1889 he became Borough Engineer and Surveyor of Walsall, and retained this post until his death, a period of 17 years. On taking up his new duties, he reorganised the department under his charge, and brought it, by his able and energetic administration, to a high state of efficiency. Devoted to his work, the growth and development of the borough brought him manifold tasks, all of which he carried out with ability and success. He was responsible for the enlargement and remodelling of the sewage farm at Bescot, where he conducted experiments on the disposal of sewage, and he also designed and carried out an additional sewage farm at Beechdale, and a storm-water system for the town drainage. When the tramways were taken over by the municipality, Mr. Middleton successfully undertook their reconstruction and extension. Amongst other works, he laid out a new cemetery, extensions of the Arboretum and other parks, and was concerned with the design and erection of a number of public buildings. He was also frequently consulted by other public authorities, including the Staffordshire County Council, and all with whom he came into contact held his personal character and professional competence in high esteem. In 1905 his health failed, and after nearly 12 months' illness, he died on the 4th August, 1906, aged 50.

Mr. Middleton was elected an Associate Member of The Institution on the 2nd February, 1892.

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GEORGE BROWN MURDOCH was born on the 3rd March, 1836, in Tasmania, where his father, an officer in the army, held a government appointment. He received his education at Glasgow Academy and at the University, and was apprenticed in 1855 to Mr. Alexander Doull, surveyor and civil engineer, of Greenwich, under whom he carried out survey work in Russia. In 1858 he went out to India and was employed for 7 years as contractor's engineer on the construction of the Great Indian Peninsula Railway. In 1871, after an interval at home, he went to Australia for Messrs. A. and R. Amos, contractors, for whom he carried out various railway lines in New South Wales and Queensland.

On his return from a second visit home in 1886 he engaged in consulting practice in Sydney. He retired from professional pursuits in 1892, when he left the colony and resided in Edinburgh until his death on the 11th May, 1906.

Mr. Murdoch was elected an Associate Member of The Institution on the 7th May, 1867.

MAGNUS OHREN, who was descended from an old Swedish family, was born at Rotherhithe, where his father followed the occupation of wharfinger, on the 8th December, 1821. His connection with the gas industry commenced with his apprenticeship in 1837 to Mr. Geddie Pearse, the Engineer-in-Chief of the British Gas Company, whose London works were in School House Lane, Ratcliff. He remained with the Company until 1846, when he went to Hamburg to assist in lighting the city with gas, but on his return to England in 1850, he was re-engaged by Mr. Pearse. The works of the Company becoming eventually too small to meet the requirements of the district, they were acquired by the Commercial Gas Company, to whom Mr. Ohren transferred his services, being appointed Superintendent of his old district as well as of Millwall. In this capacity, he carried out a very successful piece of work in the laying of a 10-inch main in East India Road, to afford a better supply of gas to Millwall from Stepney; thereby obviating the large capital outlay required for the erection of works at the former place, which had been in contemplation. The Crystal Palace District (now the South Suburban) Gas Company was formed in 1854; and in the following year Mr. Ohren was appointed Manager of the works. He subsequently became Secretary, and discharged the duties of the two offices until 1865, when they were

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divided owing to the rapid growth of the undertaking. Mr. Ohren retained the secretaryship until the autumn of 1893, when, having reached his seventy-second year, and his health being much impaired, he sent in his resignation, which was accepted with great regret.

Mr. Ohren was well known in gas-engineering circles, alike from his technical and financial connection with the industry; and by all he was highly respected. He was one of the founders of the Society of Engineers, and was a Fellow of the Chemical Society and the Royal Sanitary Institute. He acted as President of the British Association of Gas Managers in 1870, and subsequently joined the Gas Institute and the Institution of Gas Engineers. He was an auditor of several gas companies. Mr. Ohren was a prominent and active Freemason, and served several offices in connection with the craft. He died at his residence at Forest Hill on the 21st March, 1907, in his eighty-sixth year.

Mr. Ohren was elected an Associate of The Institution on the 11th January, 1859, and was subsequently placed in the class of Associate Members.

JOHN SIMPSON ROPER, born on the 13th July, 1860, was educated at the Grammar School, Lancaster, and served his articles to Messrs. Harrison and Hale, Engineers and Surveyors, of that town. Subsequently, for 2 years, he was employed as an assistant to the late Mr. James Mansergh, Past-President, on the Stockton and Darlington waterworks, St. Albans sewerage works and other undertakings. From 1883 to 1888 he held the position of engineering assistant on the Earl of Bective's estate at Kirkby-Lonsdale, where he had charge of gas and water-supply, sewerage and drainage works, and the erection of buildings and embankments. In 1889 he entered into partnership with Mr. Robert Lawson, and under the style of Lawson and Roper, subsequently Roper and Procter, carried on the business of Engineers and Surveyors in Lancaster. Mr. Roper died on the 10th May, 1907, aged 47.

He was elected an Associate Member of The Institution on the 6th April 1886.

HENRY GEORGE ARCHIBALD ROUSE, born on the 20th June, 1854, received his engineering training, with a view to his following the marine branch of the profession, in the works of

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Messrs. John Penn and Sons, of Greenwich, between 1872 and 1876. He went to sea, as third engineer of the mail steamer "Solway," in December, 1877, and served nearly 6 years afloat in the "Solway," "Marlborough" and "Chamois" as third, and subsequently as second engineer, having passed the Board of Trade examination in the latter class. In 1883 he received an appointment in the drawing office of Messrs. J. I. Thornycroft and Company, of Chiswick, where he remained a short time, afterwards relinquishing the pursuit of his profession.

Although in later years an invalid, he became well known as an authority on yachting, to which he was devoted. He held for some time the position of honorary treasurer of the Yacht Racing Association, an office which gave him a seat on the council, where his sound judgment and advice on technical matters were of great service. He designed several small yachts and did much to improve the sport in the Solent. Ill-health prevented his taking an active part in yacht racing in recent years, but he was very popular in racing circles alike for his unequalled knowledge of the sport and a keen but kindly sense of humour. His death at West Byfleet, Surrey, on the 5th November, 1906, was deeply and widely regretted.

Mr. Rouse was elected an Associate Member of The Institution on the 5th February, 1884.

WILLIAM EDWARDS SHAW, born on the 6th May, 1851, was educated at Tettenhall, and obtained his practical training in the locomotive works of the Great Western Railway at Wolverhampton, and in the office of the late Mr. William Clarke, of Westminster. He then became Agent and Engineer to his father-in-law, Mr. Henry Lovatt, Contractor, of Wolverhampton, and being subsequently taken into partnership, he was associated with that gentleman in the execution of many important contracts, among which may be mentioned the Burton reservoir, the Copenhagen tunnel and widening of the Great Northern Railway near King's Cross, a section of the Barry Railway, and widening works for the Great Western Railway. Mr. Shaw retired from business in 1890, and died at Llandudno on the 4th October, 1906.

He was elected an Associate of The Institution on the 10th April, 1877, and was subsequently placed in the class of Associate Members.

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BERNARD O'DRISCOLL TOWNSHEND, born on the 11th March, 1851, obtained his early engineering experience under his father, the late Mr. Richard Townshend,[1] then Superintendent of Keyham and Devonport dockyards and of Plymouth breakwater. On completing his pupilage, he was engaged on reservoir works near Plymouth and on the South Devon Railway. In 1876 he entered the service of the Admiralty and continued in that employment for upwards of 20 years. During this period, he twice acted as Assistant Engineer in charge of the works of repair and maintenance at Plymouth breakwater, and once, for 2 years, in charge of Alderney breakwater, the methods adopted for the repair and maintenance of which he described in a Paper[2] contributed to the Proceedings of the Institution in 1897. Between 1894 and 1897 he was in charge of the Bermuda station, and subsequently of the Eastney division of Portsmouth dockyards, for the Admiralty Works Department. After leaving the Admiralty service he acted in 1899 and succeeding years as Resident Engineer on the Devonport water-works extension, and on other works in the neighbourhood. He died at Stonehouse, Devon, on the 24th February, 1907, in his fifty-sixth year.

Mr. Townshend was elected an Associate Member of The Institution on the 2nd December, 1884.

SIR ALEXANDER WILSON, *Bart.*,[3] died at his residence, Archer House, Sheffield, on the 27th April, 1907. The son of the late Mr. George Wilson, of Broughty Ferry, he was born at Haughmill, Fifeshire, and received his early education at St. Andrew's, afterwards proceeding to Edinburgh University. On leaving the University he entered the Cyclops Works of Messrs. Charles Cammell and Company, of Sheffield, his eldest brother, the late Mr. George Wilson, having become a partner in the firm. In 1857, after passing through the various departments at the Cyclops Works, he was sent out to the United States to represent the firm, and his complete success in that mission thoroughly justified his appointment. Returning in 1859 he took up an important position under his brother. In 1864 the Cyclops firm was converted into a limited company, with Mr. George Wilson as managing director,

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[1] Minutes of Proceedings Inst. C.E., vol. xciii, p. 492.

[2] *Ibid*, vol. cxxxi, p. 307.

[3] This notice is based on the memoir which appeared in *The Engineer*, 3rd May, 1907.

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and Mr. Alexander Wilson as his assistant. The chairman, Mr. Cammell, died in 1879, and Mr. George Wilson succeeded to the position, retaining also that of managing director, both of which he occupied with distinguished ability and great advantage to the company until his decease in 1885, when his brother, the subject of this notice, was appointed managing director and deputy chairman, succeeding to the chairmanship in 1889. In that position, as in all others, he enjoyed to the full the confidence and esteem of his colleagues on the Board, and of the shareholders in the rapidly-growing establishment. Great regret was felt and expressed when, in the middle of 1901, he was obliged, on medical advice, to give up the onerous duties and heavy responsibility of managing director. Although resigning the control of the great works, Sir Alexander retained the position of chairman, which he held until the close of 1903 on the amalgamation of the business of Charles Cammell and Company with that of Messrs. Laird and Brothers of Birkenhead. With the great expansion of the business the names of Mr. George Wilson and Sir Alexander Wilson are indissolubly associated. They were both men of exceptional business ability, initiative energy and resourcefulness. When Sir Alexander assumed the managerial control, the firm gave employment to some five hundred persons: at the date of his death the workpeople exceeded 13,000 in number.

Sir Alexander (then Mr.) Wilson joined the Cutlers' Company in 1886, and occupied the chair of the guild in the Diamond Jubilee year. The baronetcy was conferred upon him shortly after the visit of Queen Victoria to the Cyclops Works in the summer of that year. As Master Cutler Sir Alexander worthily sustained the traditions of the office, discharging its many and varied duties with dignity and ability. He possessed all the qualities which fitted him for his position, and at the close of his year warm testimony was borne to the way in which he had filled the chair of the ancient guild. Although personally he took no active part in public affairs, he followed their trend with the keenest interest. Institutions and movements for the relief of the necessitous, and the welfare of the community found in him and in Lady Wilson ready and generous friends.

Sir Alexander Wilson was a Justice of the Peace for the West Riding of York and the city of Sheffield, and a member of the Institution of Mechanical Engineers and of the Iron and Steel Institute. He was also the Consul in Sheffield for Chili.

He was elected an Associate of The Institution on the 14th April, 1874.

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*** The following deaths have also been made known since the 17th May, 1907:—

Members.

ANDREWS, ARTHUR THOMAS; *died* 25 May, 1907.
ANDREWS, THOMAS; *died* June, 1907.
BARR, GEORGE MORRISON; *died* 27 May, 1907.
BROCK, WALTER; *died* 25 April, 1907.
COPLAND, *Sir* WILLIAM ROBERTSON; *died* 19 August, 1907.
FULLER, GEORGE; *died* 6 June, 1907.
HASWELL, CHARLES HAYNES; *died* May, 1907.
HEMANS, ARTHUR WILLOUGHBY; *died* 17 June, 1907.
HODGSON, HARRISON; *died* 11 May, 1907.
JENNINGS, WILLIAM TINDAL; *died* October, 1906.
KINCAID, JOSEPH; *died* 20 August, 1907.
MORRIS, FRANK; *died* 16 May, 1907.
POLLARD, JOHN; *died* 3 September, 1907.
STANLEY, WALMSLEY; *died* 3 August, 1907.
SYKES, BENJAMIN; *died* 12 August, 1907.
VERNON-HARCOURT, LEVESON FRANCIS; *died* 14 September, 1907.

Associate Members.

ARNOLD, FRANK WILLIAM; *died* 4 July, 1907.
BONHAM-CARTER, REGINALD; *died* 27 May, 1906.
GRAFTON, ALEXANDER; *died* 18 August, 1907.
KENYON, FRANCIS EDWARD; *died* 27 August, 1907.
LEE, EDWIN; *died* 2 June, 1907.
MEAGHER, JAMES JOSEPH; *died* March, 1907.
MENZIES, JOHN; *died* 21 May, 1907.

Associates.

BACHE, ALFRED; *died* 6 Sept., 1907.
EVANS, *Sir* FRANCIS HENRY, *Bart.*; *died* 23 January, 1907.
JARRAD, FREDERICK WILLIAM; *died* 21 May, 1907.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—SEC. INST. C.E., 16 September, 1907.

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Sect. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

Land-Surveying by Photography. Ræder.

(Teknisk Ugeblad, Christiania, Engineering section, 1907, pp. 59–62.)

This method, new to Norway, is called "photo-topography" or "photogrammetry." The Author took part in the compilation of the photogrammetric map, which has been constructed on the basis of Captain Isachsen's surveying expedition in Spitzbergen last summer. Instead of plotting direct on the usual board the position of objects in the survey, photographs can be employed with advantage in many places, especially where a large number of points are to be observed. Dimensions are measured from the photographs themselves.

The photographic plate or negative stands upright in front of the camera, the bottom of which is horizontal and carries the observing eye-piece at a known distance behind the negative. By means of a scale the vertical and horizontal co-ordinates of any point in the negative are measured. The camera is pivoted to rotate through successive angles of 45°; so that eight photographs form a complete panorama round the observing-station. By shifting to another station, and photographing the same points afresh, their distance from the camera can be determined. A negative of 240 to 250 millimetres (9½ to 10 inches) horizontal width is found convenient; and allows of measuring distances up to about 3 or 4 kilometres (2 or 2½ miles); with very clear light up to 6 kilometres (3¾ miles). The method is illustrated by six diagrams and three photographs.

In Austria photogrammetry is systematically carried on, and the ordnance survey is plotted therefrom to a scale of $\frac{1}{25000}$, or 2·5344 inches per mile. It is used principally for bare mountain tracts above the altitudes of trees, since forests and brushwood are unfavourable to sharp definition of spots observed. Nor is a broad flat expanse suitable for observation; but it is for steep cliffs, more or less inaccessible, that the photogrammetric method can be adopted with advantage. In Sweden, Italy and Switzerland, the plan is in use; and it is extending throughout the rest of the world.

Mr. Dahl doubts whether photogrammetry will win its way with engineers who have to survey on a larger scale. In France sufficient accuracy for business measurements required too bulky an

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apparatus. Field work, which is the strong side of the method, is rendered cumbersome by the number of signals required; and office work is decidedly so. Another inconvenience is that the result is seen as a chart; whereas in measuring estates figures are preferred. On the other hand the photographs take in a greater tract than is strictly required, and thus give opportunity for selecting alternative routes for railways or watercourses. Where the object is to furnish a chart on a small scale for more extensive investigation, photogrammetry is certainly in its proper place.

Captain Munthe considers systematic surveying by photogrammetry would encounter many economic and practical difficulties.

Captain Klingenberg points out that the Norwegian triangulation is laid out exclusively on a scale of $\frac{1}{20000}$, or 1·2672 inch per mile, whereas the Austrian scale being twice as large gives so many more trigonometrical points. In many parts of Norway it will be difficult to see the number of points necessary for employing photogrammetry; the trigonometrical measurements would have to be plotted afresh, which would entail important expenditure.

A. B.

Sea-Level round the Coast of Sweden. GUSTAF NERMAN.

(Teknisk Tidskrift, Stockholm, 1906, General section, pp. 251–3.)

The water-level of the Baltic Sea round the coast of Sweden has been the subject of observation for more than two centuries. The oldest known bench-mark was cut in 1700 by And. Davidsson on Raholmen, outside the village of Vänatjärd in Leder-Kalix parish, which is at the northernmost end of the Gulf of Bothnia. Since then more than a hundred water-marks have been placed round the Swedish coast. Celsius thought the mean sea-level in the Baltic must be sinking not less than 1·33 metre (52 inches) in a century. In 1847 it was proposed by Professor A. Erdman that the Academy of Science should arrange for daily observations of water-level at several of the light-houses; and at twelve of these the proposal was carried out in 1852–75. The observations were worked out by Dr. L. A. Forsman, and published by the Academy; and later the seaward advance of the coast-line was investigated by Dr. L. Holmström. In 1885 a parliamentary grant was voted for establishing four self-registering water-gauges south of Stockholm; and the levellings were extended northwards to the frontier, and to Haparanda at the head of the Gulf of Bothnia, so as to connect with the Norwegian and Finnish surveys. With the Danish[1] the same end has been gained by special trigonometrical levellings over Örsund at Helsingborg. These surveys, made in 1886–1905, comprise at least 6,000 kilometres (3,730 miles), much of which is over rough country, and much is

[1] See Minutes of Proceedings Inst. C.E., 1880, vol. lxii, p. 32; and 1906, vol. clxvi, p. 397.

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over islands and bays, requiring other geometrical operations for connecting no less than 2,400 water-marks with the main survey. A valuable account of the work, by Professor P. G. Rosén of the Nautical Meteorological staff, has been printed. The heights were all reckoned from a normal datum situated at the office of the general staff in Stockholm. But the Author recommends referring them to the sill of the Mälar sluice in Stockholm, which is 3·84 metres (12·59 feet) below mean water-level of the sea outside the sluice. Here the mean sea-level is 11·8 metres (38·71 feet) below the normal datum, which latter is accordingly 15·64 metres (51·30 feet) above the sill. The highest bench-mark in the survey is 599·22 metres (1,965·72 feet) above sea-level; the next in height is 521·265 metres (1,709·87 feet), where the railway crosses the frontier. Of what remains still to be done, a specially important work is the correct levelling of the River Gota, Sweden's largest water-course, and of Lake Wenner, where the prevailing winds cause variations in the water-marks. The Author, therefore, urges that the bench-marks, at two places which he indicates, should now be accurately determined and co-ordinated with the general survey. In a subsequent article (pp. 288–9) the Author's views are supported by Mr. Gust. Anderson, engineer, who follows them by a proposal for a practical method of raising the necessary funds for defraying the expense of a levelling survey by the government general staff. He recommends that the owners of water-rights should be assessed in proportion to their interest in the water flowing through their properties, as estimated by the height of fall and the quantity of flow. Such a plan would not be unduly burdensome on individual proprietors. The suggestion is offered that a start should be made from Kolbäck along the course of the Kolbäck river up to Ludvika; thence southward to the lakes feeding the Hedström river, and down along its course to its junction with the Mälar estuary at Valskog. The whole distance would be under 200 kilometres (125 miles English), and the cost would not exceed 4,000 kronor (£220). As long ago as the 27th September, 1879, a general datum-level was fixed for Prussia, to which all surveys registered in that kingdom are required to be referred.

A. B.

Road-Pavements. G. Pinkenburg.

(Deutsche Vierteljahrsschrift für offentliche Gesundheitspflege, Brunswick, 1906, vol. xxxviii, pp. 511–26, 663–76.)

The Author reviews by means of statistics and data the development of modern road-pavements from a hygienic point of view. He summarizes the practice in England, France and Germany in reference to macadam, stone sets, wood, asphalt and the new concrete methods of street-paving. On the basis of road-construction and road-maintenance the Author then treats the

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hygienic properties of each pavement, placing them in the following order:—(1) asphalt, on account of its impermeability and cleansing properties; (2) wood-pavement; (3) stone sets; and (4) macadam, with its facilities of raising dust mixed with objectionable matters.

The article is accompanied by statistical figures and historical data.

F. R. D.

Paving Streets with Small Stones. FIGGE BLIDBERG.

(Teknisk Tidskrift, Stockholm, 1905, Road and Water section, pp. 85–7.)

In substitution for macadamising, the Author has recently adopted in Gothenburg, in a modified form, a plan of paving streets with small stones, with which he became acquainted in Hanover, where it had been introduced in 1887 by Councillor Gravenhorst in the town of Stade. At the annual meeting of the Swedish Municipal Engineers' Association in 1906 he gave an account of his observations and experience. After the road-surface has been scarified, the old macadam is steam-rolled, to form the bed for paving with small stones, such as are ordinarily used for paving side-paths in town-streets. The rough blocks from the quarry are broken down to size by the blows of a stone-breaker, of which a photograph is given; it resembles a small steam-hammer or mineral stamp-head, which is worked up and down in a vertical frame from an overhead revolving shaft, and is thrown in or out of action by a treadle, enabling the workman to have both hands free for adjusting the pieces of stone to receive the blows. Both tup and anvil are wedge-shaped and blunt. The arrangement of laying the stones in paving the road-surface is in plan a succession of quadrantal circular courses, of which there are three or more series in the width of a street, so that the ends of the side courses abut nearly at right angles upon the sides of the middle quadrants, as illustrated by a photograph. In some towns diagonal courses have been tried, but look as though they were not successful. After setting on as thin a layer of sand as is practically sufficient, the stones are rammed in the usual way. The stones now generally used are 8 to 12 centimetres (3 to 5 inches) both in plan and in depth; the larger size are kept for the middle of the street, and the smaller for the sides. In Frankfurt the stone used is a kind of basalt, which breaks in more regular shapes than granite, and is carefully sorted for depths of 8, 9 and 10 centimetres (3, 3½ and 4 inches). There the cost has been given as 3·5 to 4 marks per square metre (2*s.* 11*d.* to 3*s.* 4*d.* per square yard). For a test area of 400 square metres (478 square yards) in Gothenburg the cost was 3·45 kronor per square metre (3*s.* 9*d.* per square yard); in this instance the stone was brought from Halmstad, a distance of 80 miles (English); the breaking cost 5 kronor per cubic metre (4*s.* 4*d.* per cubic yard), which would correspond with 50 to 75 öre

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per square metre paved (5½*d.* to 8½*d.* per square yard). In comparison with macadam, a street paved with small stones is more durable, freer from dust and easier to keep clean, affords a better foot-hold for horses, presents less resistance to the traffic, is about equally noiseless, looks better and costs less.

A. B.

Macadam Streets Surfaced with Liquid Asphalt.

C. C. Brown.

(Engineering News, New York, 4 April, 1907, pp. 365–6.)

This is a description of operations in Pedlands City, California. The soil is red clay, and ordinary asphalt is satisfactory but too expensive, except for the business centre. Elsewhere, crude oil on macadam has been tried and failed, except as regards dust-prevention. Finally, success was achieved with macadam surfaced with California liquid asphalt. The macadam is of metamorphic granite in two layers 3 inches to 1½ inch and 1½ to ¾ inch gauge, respectively, filled with its own screenings and watered and rolled. After drying, the liquid asphalt is applied to replace the water, about 2 gallons per square yard, and at a temperature of not less than 150° F. The specific gravity was 10° to 12° Baumé. A light sprinkling of granite dust is the final step, and is continued till the liquid asphalt ceases to appear on the surface. Heavy-grade asphalts with a light percentage of volatile oils and sediments are more quickly seasoned than the lighter grades. It has a rougher surface than asphalt pavement, is good against dust and easily cleaned by flushing.

The method of distribution is described and illustrated, two men and four horses using 3,200 gallons per eight-hour day.

The article is followed directly by two others on similar lines, one on oiled gravelled streets, and another on asphaltic-oiled and Tamper-roller compressed-dirt roads, in other Californian towns, both giving specifications.

C. O. B.

Tarring Macadam Streets in Chicago.

(Engineering Record, New York, 16 March, 1907, pp. 361–2.)

The increase of motor-car traffic has compelled the Chicago authorities to adopt protective measures, and 106,000 square yards of road macadamised with limestone, hitherto entirely satisfactory under horse traffic, have been tarred. In preparing for the latter, the surface of the macadam was broken up for 3 inches and watered, then heavily rolled. The tar, said to be free from water and from

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the lighter oils, was spread under boiling temperature by means fully described, 0·455 gallon per square yard being used. Before hardening, limestone screenings were applied and rolled, and then sand, the traffic being diverted till 24 hours after completion.

Tables are given showing cost of each detail separately, the sum total being 9·33 cents (4·66*d.*) per square yard. The results, though experience has been limited, are satisfactory.

C. O. B.

Reinforced-Concrete Road-Bridge at Stettin. WEIDMANN.

(Zeitschrift für Architektur und Ingenieurwesen, Wiesbaden, 1906, p. 489.)

This bridge was constructed to span a depression in the ground-surface, the length being 72 feet and the breadth 16½ feet. The requirements being maximum economy of construction and maintenance, a comparison was made between a bridge of reinforced-concrete and one of iron. The calculations were made for the most unfavourable loading, namely, a crowd weighing 70 lbs. per square foot, and in accordance with the ministerial regulations of 1904. The bases of the abutments are so designed that the ground is subject to a uniform pressure of 17 lbs. on the square inch. For the foundations, pillars and ribs the proportions were, 1 cement : 8 gravel, and for the foundations of the road-way 1 cement : 6 gravel. The mean compressive strength of the concrete after 28 days was respectively 2,000 and 2,500 lbs. on the square inch. The roadway itself is of cement-macadam, and the footway is covered with slabs of artificial granite. For the whole structure, exclusive of cement-macadam and artificial-granite slabs, 97 cubic yards of cement were used. Owing to the bad condition of the ground, exceptionally heavy reinforcement, to the amount of 7,300 lbs. of round- and hoop-iron, was used; notwithstanding, the total cost of the completed bridge was only £290, from which is to be deducted £29 for sheet-piling, used on account of water-infiltration, and £54 for the cast-iron parapet-railing.

E. H. S.

Concrete Road-Bridge at Ulm. NEUFFER.

(Deutsche Bauzeitung, Berlin, 1907, 5 January, pp. 1–4; 23 January, pp. 7, 8; 6 February, pp. 11, 12.)

This new concrete road-bridge over the railways at Ulm is constructed on the 3-pin joint system, and has a single arch with a clear span of 215 feet, allowing a headway of 50 feet above the rails. The rise of the arch above the abutment pin-joints is 19 feet. The south approach to the bridge has a grade of 4 per cent. and the north approach a grade of 1·2 per cent. The total breadth between the

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balustrades is 30·5 feet, consisting of a roadway 18½ feet and two footways each 6 feet. The main arch is of concrete, whilst the roadway and its supporting piers, with their overhanging bracketed footways, are of reinforced concrete. The maximum stress at any cross-section of the arch under the most unfavourable eccentric load has been accepted as 570 lbs. per square inch. The stone for the concrete consisted of—

55 per cent.	coarse broken Jura limestone . . .	⅝ to 1⅝ inch gauge.
25 „	fine „ „ „ . . .	¼ „ ⅝ „ „
20 „	limestone dust	¼ inch gauge.

The concrete mixtures for the main arches were 1 cement, 3 river sand, 5 stone; for the pin-joint abutments, 1 cement, 1 sand, 2½ broken porphyry; and for the reinforced-concrete work, 1 cement and 4½ fine gravel and sand. The time taken for building the bridge was 11 months, and the cost was £7,900, or, calculated on the concrete used—6,000 cubic yards—£1·62 per cubic yard.

The article is accompanied by numerous illustrations showing the methods of construction, as well as by complete tables on the strength of the cement and concrete used, and by data on deflection-tests.

F. R. D.

Revolving Railway- and Road-Bridge over Hamburg Harbour.

MERLING.

(Zeitschrift für Bauwesen, Berlin, vol. lvii, Parts 1-3, pp. 39-38.)

In connection with the modifications now being made in the railway communications with Hamburg, a new bridge—to serve for a roadway at the lower level and a railway above—which should be capable of being readily turned or removed, so as to give access to vessels entering the harbour, was rendered necessary. By reference to numerous photographs and a series of drawings and diagrams an account is given of this undertaking, which was begun in May, 1902, and completed in May, 1904, at a cost of £53,500. The design was the result of a competition between certain selected firms of contractors, tendering on general conditions prescribed beforehand. The structure was to be a revolving bridge driven by compressed-air and moving round a central pier. The pier which contained the pivot was hexagonal in plan; the diameter of the inscribed circle was 43·95 feet. The foundations for the pier, which are fully described, involved certain difficulties in construction, and the bed of concrete had a thickness of 13 feet. In order to render it more impervious a considerable admixture of trass was used with the Portland cement concrete. As the traffic is such that the bridge will only require to be moved at long intervals, it was considered advisable to adopt a system which should enable the requisite power to be generated slowly and stored for use. The total weight of the structure, which

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amounts to 1,000 tons, is very considerable, and the axial pillar is provided with two sets of sliding-shoes arranged on two planes 17·3 feet apart. These planes work on guide-rings of chilled iron. Compressed-air is used to work the rotating arrangements and a 12-HP. benzine-motor in connection with a high-pressure Schwartzkopf compressor serves to compress the air and store it in a series of 28 steel flasks arranged round the shaft of the central pier.

G. R. R.

New Knippels Drawbridge, Copenhagen.[1] H. C. V. MØLLER.

(Den Tekniske Forenings Tidsskrift, Copenhagen, 3 April, 1907, pp. 1-17).

To meet the present requirements of the traffic, both over and through the waterway, the existing iron drawbridge, opened in 1869, is now about to be replaced by an entirely new structure, closely alongside the present, which will continue to be used until the erection of the new bridge is completed. A long account of the old timber bridge is given by the Author, who is the Engineer and Harbour-Master; and numerous illustrated designs for the new bridge are described and criticised. Visiting North America in 1904 he obtained a sketch of a design by Mr. Strauss, which, though it had nowhere yet been executed, seemed likely to suit the requirements for the Knippels bridge; it was, therefore, made the basis for modified plans, which were then worked out by the late Councillor V. Dahlerup, and by Mr. Axel Berg, as architect.

There are two piers in the water, 90 feet apart, and 26 feet wide, with a fixed span of 52 feet between each pier and the quay-wall. The two leaves of the drawbridge over the waterway are each formed of a pair of I girders, connected by cross-bearers carrying the roadway, which has a width of 22 feet for vehicles between footpaths of 11 feet width along each side. The gradient on each leaf of the bridge is 1 in 50, rounded off at the apex. The cost is estimated at 918,000 kroner (£51,000).

The piers are erected by floating them into position over a floor of concrete laid on the dredged bed of the waterway. Each has a strong iron base-plate, stiffened by vertical ribs, and surmounted by plate-iron walls forming a caisson, which is lined with concrete, and is then sunk upon its foundation by filling its interior with concrete; a chamber is left in the top for containing the train of spur-gearing for raising and lowering the bridge. Above each pier is an arch across the roadway, carrying an overhead machine-room, in which works up and down a counterbalance-weight, arranged to bear

[1] Copenhagen lies on both sides of the Kalvebodstrand, a narrow deep strait of the Sound which separates Zealand from the smaller island of Amager. This strait forms the excellent harbour, stretching N.E.–S.W. along the south-east of the city. Knippels Drawbridge crosses the harbour from the Christiansborg Palace on the Slotsholm, the oldest part of the city, to the Christianshavn quarter on Amager.—A.B.

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through links upon the tail-end of the bridge-leaf, behind the trunnions. Each leaf will weigh about 125 tons, and the counterpoise will be 250 tons. When the bridge is closed, the counterweight is lifted off by hydraulic pressure. For opening, therefore, the counterweight has to be let down upon the tail, and then the gearing is driven by two electric motors situated in the overhead room. On closing the bridge again, the two leaves just clear each other by about 12 centimetres (5 inches). Each has, consequently, to be pushed forward through half this distance till they meet. For this purpose the pedestal-frame, carrying the trunnions of the girders and the spur-gearing, is itself carried on a rocking link, enabling the small horizontal movement of the whole to be effected by hydraulic pressure from an accumulator in the pier-chamber. Water under pressure is pumped into the accumulator and into an overhead reservoir by an electric pump, which starts automatically. The bridge is worked from the overhead machine-room; the opening or closing will occupy about 30 seconds in fair weather, and about 50 seconds in a storm.

A. B.

Traveller for the Erection of the Quebec Bridge.

(Engineering Record, New York, 23 February, 1907, pp. 198-201.)

This, the largest traveller of the kind, totally unlike any other used for cantilever erection, being of the gantry type, is in itself an engineering structure of a remarkable nature. It is made of steel, with a Z-shaped side elevation but with the central member vertical, and consists of a 54-foot by 103-foot steel tower 212 feet high, the longer side being transverse, with a 66-foot cantilever-extension in front at the top, which commands one full panel of the incompleted structure in advance of the traveller and affords support for the tackle. A corresponding projection at the base rear-end—but shorter, being 54 feet—supports the hoisting-engines and serves partially to counterbalance the load and anchorages by the provision of heavy bolts. The cross-section clears completely that of the superstructure of the bridge, so that the lateral and sway bracing of the latter can be connected as fast as trusses are assembled, thus diminishing risk from storm. The anchor-arms of the Quebec bridge are erected on staging, which for this portion, therefore, supports the traveller. On the cantilever-lengths the traveller runs forward on ways fixed to the panels as completed. The traveller-line, cast-steel wheels, and other details are fully described and well illustrated. The total weight of the structure, with hoisting-engines, tackle, etc., amounts to 2,225,000 lbs. Some of the pieces handled are 100 feet long, and, in case of several being simultaneously dealt with, as much as 500,000 lbs. weight may be thrown on the overhang.

C. O. B.

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Erection of the Cantilever-Spans of Blackwell Island Bridge, U.S.A.

(Engineering Record, New York, 2 March, 1907, pp. 284-6.)

This great bridge will comprise, commencing from the New York end, one shore anchor-span of 469 feet 6 inches, one channel cantilever-span 1,182 feet, one island anchor-span 630 feet, a second channel cantilever-span 984 feet, and a shore anchor-span of 459 feet at the Long Island end, the larger channel-span being only exceeded in length by the Forth and the Quebec bridges. The piers are of masonry. There are two continuous lines of pin-connected trusses 3,724 feet 6 inches long, 60 feet apart, with a clearance over low-water of 135 feet, carrying, by means of two decks and brackets on each side of the lower one, one carriage road, two footways and eight lines of railway, accommodating 150,000,000 passengers annually.

The island-span has been the first erected, on steel staging which will be removed to serve for the shore-spans. The channel-spans, the erection of which is the main subject of the article, are being carried out on the cantilever principle simultaneously with the shore spans; the arms from the island over the two channels being brought out to meet them in mid-channel. Besides the detail of these latter operations, the article describes the bridge generally, and gives an outline of the history of the project. The most recent report, dated 9th February, 1907, showed that of the 50,000 tons of steel of which the superstructure will be composed, 27,000 tons have been delivered and 16,000 tons erected.

C. O. B.

Piney Creek Bridge, Washington.

(Engineering Record, New York, 26 January, 1907, pp. 88-90.)

This concrete arched bridge 272 feet long, 25 feet wide over all, and 50 feet high, a roadway over water, was built as an instalment of a wider bridge to be ultimately constructed when funds should be available, the method adopted for this purpose being somewhat unusual. The plans were made to permit of construction in two symmetrical longitudinal halves, each having its axis parallel to that of the completed bridge and 20 feet from it. The separate halves form complete and independent structures, and after the completion of the second half, at a clear distance of 15 feet from the first half, the two will be connected by a reinforced-concrete platform at the roadway-level, and the inner parapet of the first bridge removed, giving a width over all of 65 feet.

The half now under construction includes a single parabolic arch 125 feet span, and 39 feet rise, with abutments of rectangular cross-walls extending back about 72 feet at each end. The spandrels are of similar form, but having two longitudinal inner walls instead of

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one. The arch is 5 feet thick at crown, and 7 feet at springing. The roadway, 20 feet wide, is a reinforced-concrete slab 10 inches thick. The whole work is reinforced with steel in a manner only to be understood by reference to the numerous illustrations accompanying the article, which also show the position of the expansion-joints. The concrete proportions were 1 : 2½ : 5.

The description of the centreing is given very fully, as well as other features in connection with the erection. The cost is expected to be about $49,731 (£10,360 12*s.* 0*d.*).

C. O. B.

Helicoidal Railway-Viaduct in Paris. R. Bonnin.

(La Nature, Paris, 24 November, 1906, pp. 403–6.)

The Metropolitan Railway, after crossing the Seine near the Austerlitz bridge, describes a sharp curve with a radius of only 246 feet, in order to continue its course along the quays. Partly for æsthetic reasons it was considered expedient to construct the girders for the viaduct to the same curve as the rails, and since, in addition to the curve, there is a falling gradient of 1 in 25 after crossing the bridge, many difficulties were entailed in the design of the requisite metal work. By means of an illustration of the completed structure and plans and sections, together with diagrams, the mode of forming the viaduct with a helicoidal curvature is explained. The two main girders, which are 26·2 feet apart from centre to centre, are continuous throughout their entire length, and embrace a pivoted metallic support fixed against the masonry of the bridge, having a joint at the base and a second pivoted support also jointed at base midway between the bridge and the shore end of the viaduct, on the line of the quay. These girders bear at the shore end on rollers supported on masonry piers, to allow for expansion and contraction. The side girders of the viaduct are formed of upper and lower members with inclined braces and vertical struts, these latter being trussed to resist the thrust due to the curved form of the structure. The floor of the viaduct is supported on the bottom of the girders, and is strongly tied by curved braces to the upright members. It is stated that this viaduct is interesting as being the first attempt made to substitute a wholly curved metal girder for one polygonal in plan. The two girders are of course not uniform in curve, being built to the proper radius in each case, but the sections are alike. The steelwork throughout is designed so that the stress on any member shall not exceed 10 kilograms per square millimetre (6·35 tons per square inch). The work has been carried out by Messrs. Daydé and Pillé, who also built the Passy bridge for the Metropolitan Railway.

G. R. R.

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Reinforced-Concrete Viaduct of the Richmond and Chesapeake Railway at Richmond, U.S.A.

(Engineering Record, New York, 2 March, 1907, pp. 226-7.)

This is a description of a novel development of reinforced-concrete application, this material, which is exclusively employed, being used in a similar form to that usually given to timber or steel trestle-structures, the only exception being that the bracing is horizontal throughout. The viaduct is for a single line, and is 2,800 feet long and 18 feet to 70 feet high, the piers, of the ordinary American trestle type, being formed of battering columns square in section in groups of four, the higher ones being connected by horizontal bracing. The spans are of two girders rectangular in cross-section and 6 feet 9 inches apart, centre to centre, varying in dimensions according to the spans, which range from 23 feet 6 inches to 67 feet 5 inches, and connected at top by a 3½-inch slab.

The reinforcement of columns and girders, which is on the Kahn system, is well shown in the illustrations. The maximum loading is a train of electric cars each 54 feet over all, weighing 150,000 lbs., on four-wheeled trucks placed 33 feet centre to centre, the truck wheel-base being 7 feet. The concrete is stressed compressively to 500 lbs., and in shear to 50 lbs. per square inch, the steel 16,000 lbs. tensile, 60,000 lbs. (*sic*) compressive, and 10,000 lbs. in shear, per square inch, the moduli of elasticity being as 1 to 12 in the two materials.

The concrete in footings consists of 1 : 3 : 6 (granite) and elsewhere of 1 : 2 : 4. The means provided for expansion, the moulds, and methods of construction are fully dealt with. The rails on 9-foot sleepers, 8 inches by 8 inches and 12 inches apart on centres, are supported on 6-inch by 12-inch stringers placed directly over the girders.

The longest span deflected ⅛ inch under its weight (54 tons) when the supports were removed.

C. O. B.

Erection of El Rodeo Viaduct, Guatemala Railway.

(Engineering Record, New York, 2 March, 1907, pp. 270-1.)

This steel structure is of the ordinary trestle type usual in America, of braced piers 30 feet longitudinally and 14 feet 10 inches wide at top, battering transversely, and singly triangulated girders with vertical struts at the lower apexes. Three of the 75-foot spans being on a sharp curve, the construction on the cantilever plan entailed unusual operations, owing to the want of straight alignment, these spans being chords of an arc of 955 feet 6 inches radius. A travelling-derrick is employed, with its truck and

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hoisting-engine forming the counterbalance on the finished span, a 60-foot boom projecting over the next span to be erected. The process involves horizontally three positions for each span during erection, the first being that in which it is erected from the preceding span, viz., exterior to the curve, the second that in which it serves for the erection of the succeeding span, viz., inside the curve, and the third after the derrick is moved on, when it is placed in its final position as a true chord of the arc. The tower-tops on the curved portion are slightly extended laterally to meet this requirement.

Diagrams are given to illustrate these operations, as well as full details of the whole work.

C. O. B.

Detroit River Tunnel of the New York Central Lines.

(Engineering Record, New York, 2 March, 1907, p. 260-3.)

This work replaces a train-ferry between Detroit, Michigan, and Windsor, Canada, the traffic through it to be worked electrically. The plan of construction is novel, and was chosen in preference to that of the shield system. As regards the subaqueous portion, a channel is dredged across the river for about the depth of the exterior twin steel tubes, which are sunk into it.

The tubes, 20 feet in diameter, are 26 feet 4 inches apart, on centres, and are of $\frac{3}{8}$-inch plates with caulked lapped joints built on shore in sections 262 feet, 6 inches long, launched, floated to position, and sunk on a steel grillage with alignment-beams laid in the trench, one grillage to each joint. The exterior of each tube is strengthened with vertical transverse diaphragms, 12 feet apart, of $\frac{3}{8}$-inch plates stiffened by flange-angles, both radial and at the outer edges, the latter being approximately 28 feet square. Between these, jacketing the tubes, 1:3:6 concrete is sunk through water, forming a mass 58 feet 8 inches wide and 30 feet 10 inches deep over the two tubes. To resist the pressure, and to prevent deformation in handling, temporary steel diametrical struts are employed inside the tubes, which are removed as a 20-inch lining to each tube of 1:2:4 concrete is placed, reinforced by 1-inch horizontal rods, 18 inches apart, 6 inches from interior surface. This subaqueous tunnel, 2,622 feet 6 inches long, laid about 70 feet below water, is approached by land concrete twin tunnels 2,129 feet long at the Detroit end and 3,192 feet at the Windsor end. There is an interesting account of the launching, sinking and other operations.

C. O. B.

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Gradient Correction in the Battery Tunnel, New York.

(Engineering Record, New York, 2 March, 1907, pp. 286–8.)

The two cast-iron tube single-line tunnels from Battery Point, New York, to Brooklyn, having got out of vertical alignment, are being corrected by raising the roof in parts and depressing the invert in others. The removal of the segments and substitution of others of different shape, so as to make the top and bottom, for certain lengths, partly egg-shaped, involves a series of most delicate and difficult operations under a heavy pressure of fine, soft, wet material, the power being supplied by special 60-ton hydraulic jacks, which are fully described. The operations were partially explained in the *Engineering Record* of the 29th September, 1906, and the great detail in which the description is now continued is impossible of intelligible abridgment. Views and diagrams of the work and of the appliances used help much in the comprehension of the undertaking, which, so far, has been successful.

C. O. B.

Electric Traction on the Vienna Metropolitan Railway.

A. Solier.

(L'Éclairage Électrique, Paris, 1907, vol. l, pp. 51–5 and 80–8.)

This article contains a description of the system of electric traction which has been adopted for the Vienna Metropolitan Railway, after an investigation of the problem had been made and different schemes had been presented for the approval of the Austrian Minister of Railways. The problem involves the haulage of trains weighing nearly 130 tons without the locomotive on a track having a maximum gradient of 30 in 100. Trains are run at short intervals of 2½ minutes, and contain six coaches in winter and seven in summer, with the exception of Sundays, when the number is ten. The maximum speed is 31 miles per hour, and the weight on one driving-axle must not exceed 14¼ tons.

The system adopted is that proposed by the Krizik Company, and employs high-tension direct current passing through four motors in series on a locomotive. There are two overhead wires with a pressure between them of 3,000 volts, and the running-rails serve as middle and neutral conductors, so that the pressure between either wire and the rail is 1,500 volts. The locomotive has two driving-axles, each of which is driven by two motors connected in series across an outer and the middle conductor. These motors are suspended on opposite sides of the axle, and drive it by means of identical pinion-wheels on the two motor-shafts gearing in, at opposite ends of a diameter, with one large toothed-wheel on the driving-axle. The conditions of service on the line, with frequent stops and starts, and only short periods of full speed, make the use of the direct-current series-motor especially advantageous, and by

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using these 750-volt motors in series the line-pressure may be quadrupled and the use of sub-stations over a much longer portion of the line than would otherwise be possible may be avoided. As the rails are only used as neutral conductor, their condition, owing to the weather, does not affect the operation of the locomotive; and as the current is produced by two independent groups of generators, in case of accident to one of the groups or to one of the overhead wires the service may be maintained at half-speed by supplying the locomotives from one side only of the three-wire system. Similarly, if one half of the electric equipment of the locomotive gets out of order, the remaining half, branched across the other side of the system, ensures the propulsion of the train. The regulation of the system on starting and in getting up speed is best understood by reference to the Author's diagram of the controller-connections. Another diagram shows the general connections on the locomotive. The Author describes the overhead equipment, the construction of the motors and the dimensions of their parts, the special form of controller, and the circuit-breakers, resistances, and other forms of apparatus on the locomotive. The motors are each of 130 HP. and are built for 750 volts, 134 amperes, and 545 revolutions per minute. Tests of the system have been made on an experimental track and have given good results.

W. C. H.

Tasmanian Railways.

(General Manager's Report for the year ending 30 June, 1906.)

	1906	1905
Miles open—		
3-foot 6-inch gauge	439·25	439·25
2-foot gauge	23·25	23·25
Total	462·50	462·50
	£	£
Earnings	241,188	243,566
Working-expenses	172,601	171,630
Net revenue	68,587	71,936
Interest earned (per cent.)	1·74	1·83
Passenger-journeys	860,519	823,911
Goods and minerals in tons	399,487	393,838
Receipts per train-mile	61·19*d.*	61·79*d.*
„ „ mile worked	£513·43	£518·48
Expenses per train-mile	43·79*d.*	43·54*d.*
„ „ mile worked	£367·43	£365·36
Net receipts per train-mile	17·40*d.*	18·25*d.*
„ „ „ mile worked	£146·00	£153·12
Percentage of working expenses to revenue	71·56	70·46
Train-mileage	945,918	945,852
Average train-mileage per mile worked	2,013	2,013
Engine-mileage	1,142,537	1,138,415
Average distance travelled per passenger in miles	25·23	25·16
Average distance hauled per ton in miles	25·46	37·58

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Sub-division of Working Expenses.

	1906		1905	
	Total	Per Train-mile.	Total.	Per Train-mile.
	£	d	£	d.
Maintenance	53,416	13·5	54,517	13·9
Locomotive	65,831	16·7	63,542	16·1
Traffic	44,585	11·3	43,808	11·1
General	8,769	2·2	9,763	2·4
Totals	172,601	43·7	171,630	43·5
Cost of construction and equipment	£3,926,713		£3,920,508	
Ditto per mile	8,490		8,476	

Rolling-stock return—	Locos.	Cars.	Wagons.	Locos.	Cars.	Wagons.
3-foot 6-inch gauge	69	197	1,504	69	197	1,495
2-foot gauge	7	6	61	7	6	61
Totals	76	203	1,565	76	203	1,556

The report includes a comparative table relating to all Australian railways, omitting those of Western Australia, as under :—

	New South Wales.	Victoria.	South Australia.	Queensland	Tasmania.
Maintenance per mile £	160·30	148·00	117·00	92·67	113·70
,, ,, train-mile d.	10·92	13·35	12·60	13·09	13·50
Locomotive-expenses per train-mile d.	21·38	20·30	23·91	15·33	16·70
Traffic-expenses per train-mile d.	12·77	14·96	9·75	9·92	11·30
General charges ,, ,, d.	1·63	1·16	1·08	0·89	2·20
Total per mile worked £	685·70	553·00	438·00	277·69	367·40
,, ,, train-mile d.	46·70	49·77	47·34	39·23	43·70
Percentage of working-expenses to revenue	54·51	52·23	56·63	55·84	71·56
Train-miles run per mile	3,524	2,666	2,219	1,698	2,013

The General Manager is unfavourable to the introduction of motor-carriages, preferring tank-engines drawing two or three cars, and instancing the action in this matter of English railway companies where steep grades prevail.

C. O. B.

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Western Australian Railways.

(Commissioner's Report for the year ending 30 June, 1906.)

	1906		1905	
Mileage opened [1]—	M. C.	M. C.	M. C.	M. C.
Double	78 16	1,606 70	74 33	1,604 96
Single	1,528 54		1,530 63	
Sidings		235 40		226 8
Mileage under construction		121 62		31 0
Earnings—		£		£
Passengers		485,674		534,549
Goods and miscellaneous		1,148,770		1,075,580
Total		1,634,444		1,610,129
Working-expenses		1,201,753		1,256,003
Net revenue		432,691		354,126
Percentage of working-expenses to revenue		73·53		78·01
Receipts per train-mile		89·98*d.*		90·18*d.*
Working-expenses per train-mile		66·16*d.*		70·34*d.*
Number of employees		6,722		6,860
Train-mileage		4,359,633 [2]		4,285,235
Engine-mileage		5,517,151		5,465,914
Passenger-journeys		12,816,766		11,845,439
Goods-tonnage		2,328,723		2,416,799
Live-stock tonnage		28,850		26,912

Detail of Working Expenses per Train-mile.

	d.	*d.*
Locomotive power—		
Wages	15·39	16·50
Repairs	6·06	5·48
Carriages and wagons	6·01	5·74
Replacing obsolete stock	2·23	2·26
General	1·49	2·34
Total locomotive branch	31·18	32·32
Electrical	0·95	1·09
Maintenance	14·71	17·79
Signals	0·48	0·39
Traffic	16·80	16·93
General	2·04	1·82
Total	66·16	70·34
Rolling-stock—		
Locomotives	326	327
Carriages and vans	447	431
Wagons	6,143	5,704
	£	£
Capital expenditure	9,965,940	9,808,458
Interest	348,467	331,382

[1] The gauge of these railways is 3 feet 6 inches.—C. O. B.

[2] This increase is mainly due to new methods of computation agreed to by the railway systems of the Commonwealth. There has been practically no increase in actual train-mileage.—C. O. B.

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The figures for the Cossack and Raebourn Tramways are not included in the above. This is so isolated from the general system that the Commissioner has frequently urged the Government to place it under another department. The unfavourable working is shown by a Table in the appendix giving the gross earnings, from inception to date, as £42,411 5*s.* 2*d.*, and the expenditure, including interest, £62,241 7*s.* 7*d.*, resulting in a loss of £19,830 2*s.* 5*d.*

The employment of motor-coaches for the smaller services of the railway system generally is contemplated.

The Commissioner raises the important questions, to which he draws the attention of Parliament:—(1) Are the railways to be worked on commercial lines, so as to produce a surplus over and above working expenses and interest? or (2) Are the railways to be conducted so as to give the greatest possible service to the public at the lowest possible charge consistent with payment of working expenses and interest? The Commissioner proceeds to show that, under certain proposals of the Government in connection with use of native coal, reduction of freights, wages laid down by arbitration courts, construction of directly non-paying spur-lines, etc., a surplus cannot long be maintained. A definite policy for the future is therefore desirable. C. O. B.

United States Railways.

(Statistics for the year ending 30 June, 1906.)

(Railway Age, Chicago, 8 March, 1907, pp. 318-9.)

Of 313 railways 206,960 miles are represented in these figures, or 94 per cent. of the whole, the rest being said to be those of small branches not affecting totals or comparisons to any great extent. The particulars given are mileage, single, double, triple, quadruple, and sidings, and mileage protected by block system, number and weight of rolling-stock, capitalization, number and mileage of passengers and receipts per mile, tons, mileage and receipts per mile of goods, percentage of working expenses, earnings and expenses, numbers and classes of employees' wages, accidents, etc. The comparison in most cases is with the figures of the previous year, but in some cases with those of 10 years ago. The percentage of increase in the latter case might be summarised as under:—

	Per Cent.
Open line	20·9
Single mileage	31·7
Locomotives, number	31·7
,, weight	82·8
Freight-cars, number	51·5
,, ,, weight	95·3
Passengers carried one mile	88·6
Tons of goods ,, ,,	124·3
Gross earnings	101·7
Working-expenses	98·2
Wages	94·3
Interest and dividends	70·5
Taxes	72·4

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The average receipts per passenger-mile have decreased 0·4 per cent., and for goods-ton-mile 6·9 per cent. in the same period.

C. O. B.

65-*mile Inter-urban Railway in Texas.*

(Engineering Record, New York, 22 December, 1907, p. 47, supplement.)

This line, equipped on the General Electric Company's direct-current system, will be worked at considerable speed, for though the 65 miles will only be covered in 2½ hours, the schedule includes 15 minutes slow running in streets, and stoppages about every two miles. The main power equipment will include two 1,000-kilowatt Curtis turbo-generators, working under a steam-pressure of 150 lbs. at the throttle, with 125° superheat. The turbines will operate condensing. Current will be generated at 2,200 volts and 25 cycles, and stepped-up for transmission to 19,100 volts.

For exciting the fields, two 35-kilowatt generator-sets will be provided. The three-phase current from each of the turbo-generators will be transformed in a set of three 330-kilowatt air-blast transformers, with one as a reserve. The rotary-converter equipment is a special feature of interest which is described. The cars will be of the standard inter-urban type, each 50 feet long and equipped with four 75-HP. standard direct-current motors with the Sprague General Electric Company's M system of multiple-unit control.

C. O. B.

Railway Development in the German African Colonies.

SCHWABE.

(Deutsche Bauzeitung, Berlin, 2 January, 1907, pp. 6-7.)

The Author describes the development of the railway systems in the German African Colonies. This development is summarised in the following table:—

Name of Railway and Colony.	Miles Opened.	Miles under Construction.	Miles Projected.
German East Africa—Usambara Railway	83	..	..
„ „ „ Dar es Salaam–Mrogovo	14	130	..
Togo—Lome–Anecho	28	..	..
„ Lome-Palime	..	76	..
Kamerun—Duala–Manenguba Mountains	..	..	100
German South-West Africa—			
Swakopmund–Windhuk	240	..	..
Lüderitz Bay–Kubub	86	..	..
Continuation to Keetmanskoop	..	..	113
Windhuk–Rehoboth	..	..	62
Otavi Railway	354	..	..

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The Dar es Salaam Railway is being completed at the rate of 9·5–12·5 miles per month, and is being financed by a company with a capital of £1,000,000. The two railways, Lome to Palime and the Lüderitz Bay to Kubub, are being constructed by the Government at the estimated costs of £4,800 and £4,500 per mile. The continuation of the latter railway to Keetmanskoop will cost £1,000,000. The Otavi Railway has been constructed by a private company on a narrow-gauge (2-foot) system in 2½ years at a cost of £2,060 per mile. The article contains further descriptions of the lines and of some of the difficulties overcome.

F. R. D.

Shantung Railway. MEYER.

(Deutsche Bauzeitung, Berlin, 1907, 16 February, pp. 93–6; 23 February, pp. 110–4; 6 March, pp. 131–4.)

The Shantung Railway, completed in 1904, is about 245 miles long, running between Tsingtan and Tsinanfu, the capital of the province of Shantung, with a branch line of 24 miles to the Poschan coalfields. The longitudinal section shows that the main line is made up of 42 per cent. level, 29 per cent. rise, and 29 per cent. fall, with a maximum grade of 6 per cent. The permanent-way has been constructed to sustain ordinary traffic at a speed not exceeding 37·5 miles per hour. The article contains detailed accounts of the survey, as well as full particulars with regard to the cost of land, labour, transport and materials. The survey covered an area of a strip of land varying in breadth between 500 and 2,000 yards, and cost about £36 per mile, being completed at the rate of 10 miles per month. The land was expropriated in accordance with Chinese law, 1·1*d.* being paid per square yard, with a surcharge of 8 per cent. for land in crop and near the townships. The earthwork was sublet in contracts of 6 miles in length, and was paid for at schedule prices, 1·4*d.* per cubic yard for ordinary earthwork, and 10*d.* per cubic yard for rock. All bridges and culverts were standardized, as well as the wooden and steel scaffoldings used for erection.

The railway was 5 years in construction and cost:—

	£
Land	89,700
Earthwork	148,000
Level crossings and fencings	2,700
Bridges and culverts	728,000
Permanent-way	759,000
Signals, blockhouses, etc.	13,200
Stations	106,000
Repairing-shops, etc.	85,000
Materials (coals, etc.)	310,000
Administrative expenses	203,000
Interest on capital, etc.	200,000
	£2,644,600

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or, including interest on capital, about £9,200 per mile. The gross receipts of the railway in 1905 were about £680 per mile, of which two-thirds were derived from goods-traffic. The working-expenses for the same year were £265 per mile.

The article is accompanied by numerous photographs of the types of bridges, and by plans and sections of the line.

F. R. D.

Mallet Articulated Compound Locomotives.[1]

(American Engineer and Railroad Journal, New York, October, 1906, pp. 371-6.)

The Great Northern Railway (U.S.A.) has recently received delivery from the Baldwin Locomotive Works of five Mallet articulated locomotives which have the distinction of being the heaviest locomotives in the world. They have each a weight of 355,000 lbs., of which 316,000 lbs. are on the drivers. This weight does not include the tender, which brings up the total weight of the complete machine to 503,000 lbs. The satisfactory service of the locomotive of this type on the Baltimore and Ohio Railway during the past twelve months has proved the practicability of this monster machine for service under the most difficult conditions of grade and curvature. Mr. Muhlfield, General Superintendent of Motive Power on the Baltimore and Ohio Railway, stated in his Paper before the New York Railroad Club in February, 1906, that the locomotives had given entirely satisfactory results with respect to design, maintenance and operation. There had been no trouble from priming, and the results accomplished through the distribution of work over four instead of two main crank-pins and auxiliary parts had been markedly satisfactory. It was found that this locomotive would haul a heavier train over the same grades than two consolidation-locomotives which, together with tenders, weighed nearly 200,000 lbs. more than the Mallet engine.

The Great Northern engines differ from those on the Baltimore and Ohio Railway in the addition of leading- and trailing-trucks, type of boiler, and in many of the details. While they are greater in total weight they are somewhat less on the drivers than in the Baltimore and Ohio engine. The steam-pressure is 200 lbs. instead of 235 lbs., but that is more than equalized by the use of larger cylinders, so that the theoretical tractive force is slightly greater than in the Baltimore and Ohio engine. The general design of the engines and a number of the details are shown by figures in the text, and a tabulated statement of the general dimensions, weights and ratios is given.

J. M. M.

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[1] Minutes of Proceedings Inst. C.E., vol. clix, p. 390, and vol. clxiii, p. 403.

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Crude Oil for Preserving Sleepers.

(Railway Age, Chicago, 8 February, 1907, p. 180.)

Crude oil from California of very low gravity, with about 75 per cent. asphaltum, and the rest light oils which vaporise on being heated, have been used as a successful preservative for pine sleepers on the Atchison, Topeka, and Santa Fé Railway. The oil, heated to 180° F., is forced in at a pressure of 150 lbs., 4 to 8 gallons being absorbed per sleeper. The oil at ordinary temperature is like molasses, but when heated becomes sufficiently fluid for penetration, and by applying a light vacuum at the close the pores are sealed so that they can be handled without difficulty. The life of the sleepers has been so much extended by this process that the Company have decided to adopt it while continuing the use of creosote for bridge-timber and piling.

C. O. B.

Train-Shed of the Lackawanna Terminus at Hoboken.

(Engineering Record, New York, 19 January, 1907, pp. 78–9.)

This departure from the usual type, though much criticised, has been pronounced completely successful. The novelty consists in the improvement in ventilation caused by having extremely low short-span bays, covering only two lines, with their adjoining platform, and only high enough over rails to clear locomotive-funnels.

The shed is 607 feet long, of six bays each 43 feet 4½ inches span, one 35 feet 10 inches and one 30 feet 4 inches. The columns dividing the bays and supporting the roof are 27 feet apart, and each pair carries a transverse steel girder slightly arched at centre and supporting the purlins, between which are reinforced-concrete slabs, broken only by the three continuous glazed skylights, one over each platform and one at centre, and by the ventilation-openings over the locomotive funnels, which are the necessity of the plan. These consist of a pair of built-up steel sections, each encased in a concrete slab 5 inches thick and 4 feet 4½ inches high, extending the whole length of the shed and flush at the bottom with the lower flange of the main transverse girders, and projecting 1 foot above the top of the roof. The portions of the main girders between the sides of each pair of the ventilator-slabs are also encased in concrete.

Not only are gases and exhaust steam completely carried directly out of the station through these openings, but also a considerable portion of the heat radiated from the locomotives, and experience, assisted by comparative thermometer-readings under this and ordinary high roofs in the same neighbourhood, showed the air under the low roof to be 3° to 5° lower in temperature. Naturally, economy both in material and in cost of erection is in favour of the

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type decided on. The article contains a number of details as regards the structure generally, which include a plan for supplying steam to the gutters of the roof, so that snow may be melted and carried to the down pipes, and shovelling thus avoided.

The concrete was proportioned 1 : 2 : 4, and in order that it should flow easily round the expanded metal which formed the reinforcement of the roof-slabs, the stone was gauged to $\frac{3}{4}$ inch. The casing for the concrete was supported by the steel framework of the roof itself. C. O. B.

Manufacture of Railway-Car Axles. HENRIK V. VON Z. LOSS.

(Journal of the Franklin Institute, Philadelphia, January, 1907, pp. 1-29.)

The Author points out that the introduction of the large railway-cars having a capacity of 55 tons necessitated a change from the cast-iron wheels, hitherto in use in the United States, to cast-steel wheels, and further required not only stronger axles as regards increase in scantling, but more particularly an improvement in the manufacture. The present method of manufacture, consisting of forging by hammering with subsequent annealing and straightening, was crude and involved not only large wastes both in the material and labour, but had the further great disadvantage of "putting work" into the steel at the wrong place. To obtain the best results the forging should be continued until the temperature of the piece falls below 1,200° F., and the annealing temperature should be 1,500° to 1,800° F. The importance of the subject will be gathered from the statement that the total tonnage of axles per annum is 225,000. The analysis required by the specification of the Pennsylvania Railway is given, namely: carbon, 0·40 per cent.; manganese, not above 0·50 per cent.; silicon, 0·05 per cent.; phosphorus, not above 0·05 per cent.; sulphur, not above 0·04 per cent. The Author describes the main physical tests these axles have to undergo, and discusses the question whether the car-axle should be forged entirely smooth between the wheel-seats, or whether it should be rough-turned, and prefers the latter, because the rough forging leaves the product very much unbalanced. On the other hand, the tough surface-skin produced by the forging enables the axle to withstand a far greater number of blows in the impact-testing; he gives a case in which axles withstood 21 blows when rough-turned, and the same class smoothed-forged withstood 78 blows.

The Author then describes in detail the various objections to the present method of manufacture, after which he proceeds to describe certain new methods which have been proposed. The first of these is an ingenious method of end-rolling, in which a round bar is fed endways between a pair of rolls. He also describes a method of cross-rolling, the great objection to which lies in the bad twisting-effect caused by the variation in the peripheral speed of the rolls.

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Neither of these methods has been practically adopted, and the next step in the evolution of axle-manufacture which the Author describes is known as the Mercader process. This method consists in placing a rolled bar in a split die, the inner contour of which is that of the finished axle. The die slightly grips the blank at its middle, and the blank is expanded into the die by needles pushed in at each end by hydraulic pressure. This method had several advantages, and many axles were made at the Howard axle-works at Homestead and a few of them are to-day in service on the Pennsylvania Railway. There were however vital objections to the method, as, for instance, the difficulty in guiding the needles centrally and the want of rigidity owing to the great length of the pushing-needles as compared to their diameter. Some railway officials also objected to the large hole, $3\frac{1}{4}$ inches in diameter, which theoretically would reduce the strength of the axle by 20 per cent. The advantages and disadvantages of this process are fully considered, and photographic reproductions of such axles are given. The Author concludes with the description of a new method, invented by himself, which is an adaptation of an "upsetting-machine" designed by him for the Pencoyd Ironworks, for the manufacture of bridge eye-bars. Detail sectional drawings are given of the machine which consists of two horizontal and two vertical hydraulic rams. The horizontal rams are compound, that is to say, the piston of one ram forms the cylinder for the piston of the second ram. The outside ram, which effects the upsetting of the ends of the axle, is able to exert a pressure of 1,000 tons. The machine measures about 30 feet over all, is 8 feet wide, and stands about 11 feet above the shop-floor, and the Author estimates that the cost of installation is about 40,000 dollars, if low-pressure water is available. He describes the machine in great detail, and gives a comparative estimate of the cost of manufacture by the new process and the old forging-process. It would appear that, so far, a hydraulic machine of this kind for forging has not been built, but the Author exhibited a model made in hard wood —to $\frac{1}{8}$th scale—in which a number of "axles" had been "upset," but the material used consisted mainly of linseed-oil, white lead, glue, and some sugar or molasses, a mixture which is accepted by the United States Patent Office as a guide to its decisions regarding the flow of metal (? steel).

H. R. S.

Effects of the San Francisco Earthquake on Engineering Constructions.

(Proceedings of the American Society of Civil Engineers, New York, vol. xxxiii, pp. 229–354.)

An investigation of the effects of the earthquake of the 18th April, 1906, and of the subsequent fire on structures and engineering works generally was undertaken by a Committee of the San Francisco Association of members of the American Society of Civil Engineers.

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Sub-Committees were formed to investigate:—(1) the geological causes; (2) effects on buildings; (3) on waterworks; (4) on lighting and street-railway transport; (5) on sewers; (6) on railway structures; (7) on highway structures.

Some of the principal conclusions arrived at were:—(1) that the earthquake was due to the relief of accumulating stresses in the earth's crust by a movement along a previously known fault-plane; (2) that a building designed with a wind-bracing to resist 30 lbs. per square foot will safely resist the stresses induced by a shock of equal intensity to that experienced; (3) that well-built earthen dams for waterworks prove to be able to withstand shocks, and that greater attention should be paid to the location of water-pipes so as to avoid geological faults; (4) that the cable system of traction suffers by the slots closing, but the overhead electric trolley system remains undamaged.

The reports are accompanied by photographs, which, apart from the text, form an interesting study of the effect of this disastrous shock.

A special feature of interest brought out in the report is the straight fault-line running in a N.W.–S.E. direction, which formed a plane of shear, in some places the surface being displaced as much as 20 feet on the west side of the line towards the north.

R. S. B.

Design of Reinforced-Concrete Retaining-Walls. E. GODFREY.

(Engineering News, New York, 18 October, 1906, pp. 402-3.)

A form of reinforced-concrete retaining-wall is advocated in this article, of which the cross-section consists of a thin vertical wall of reinforced concrete and a thin horizontal reinforced slab of concrete together forming a letter L, the interior angle of which is strengthened with stepped concrete; the weight of the earth-filling over the horizontal slab is made use of to give stability to the structure. Every 7 feet a triangular rib is introduced, two sides of which are formed by the L and the third side by the line joining the extremities of its vertical and horizontal limbs. In these positions angles are introduced into the vertical wall and the horizontal slab, and rods starting off at right-angles to each are fixed by two nuts on their screwed ends to corresponding points in the vertical and horizontal angles. As the space in the ribs between these rods is filled with concrete, the rods are held fixed and they anchor the vertical wall to the horizontal slab, which in its turn is kept in position by the weight of earth standing on it. The vertical wall and horizontal slab are reinforced between the ribs with steel rods placed near to the face which the pressure would put into tension.

A. W. B.

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Large Reinforced-Concrete Tiles.

(Engineering News, New York, 28 March, 1907, pp. 358–9.)

Large concrete tiles 52 inches by 26 inches, with a weather-surface of 48 inches by 24 inches, $\frac{7}{8}$ inch thick and reinforced with a sheet of No. 18 expanded metal near the under surface, are being used in several large manufacturing buildings in the United States. The tiles, which are of 1 cement to 3 sand, have suitable projections for interlocking and hooking to purlins, no rafters or sheathing being necessary. Nails, wires or other fastenings are also dispensed with. The weight is 13 lbs., the safe-load 150 lbs., and the breaking-load 250 lbs. per square foot, the minimum slope in use being 1 to 6. The interlocking side-joints allow $\frac{1}{4}$ inch play for expansion and contraction, and the lap at the ends is 4 inches. They are allowed 6 weeks to 2 months to set.

C. O. B.

Triumph of Reinforced Concrete. G. Chertous.

(La Nature, Paris, 3 November, 1906, pp. 353–4.)

By reference to a series of illustrations some singular settlements are shown in certain large storehouses (silos) recently built on made ground in the new Port of Tunis.[1] The buildings were constructed of reinforced concrete, and were hastily erected on insufficient foundations. The result was that a five-storey building, 65·6 feet in height, occupying an area of 183·7 feet in length by 49·2 feet in width, heeled over on its longer side, until the walls were no less than 11·48 feet out of the upright; but the remarkable feature of the accident was that there was not a single crack of any kind in the concrete. In order to reinstate the structure, the engineers loaded the reverse side of the building with iron and with sand, and in 20 days they succeeded in bringing the warehouse again into a vertical position, when all that was necessary was to add an additional storey, to make up for the shrinkage, and the building is now upright, with a total height out of the ground of 78·6 feet. Shortly after the defects had been remedied, an adjacent warehouse, exactly similar in design and also constructed in reinforced concrete, began to settle, and in a few hours sank in the opposite direction to such an extent that the front wall, 72 feet in height, was 19·36 feet out of the upright. It is stated that this building also remained free from cracks, the glass in the windows was uninjured, and the floors were intact. These singular accidents bring into much prominence the rigidity and strength of armoured concrete.

G. R. R.

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[1] See Minutes of Proceedings Inst. C.E., vol. cxlviii, p. 385.

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Reinforced-Concrete Warehouse, Chicago.

(Engineering News, New York, 28 March, 1907, p. 364.)

In the construction generally of this four-story building there is no departure from methods now usual, but the arrangement for the reinforcement of the columns is novel and worthy of note as greatly facilitating construction. There are eight vertical twisted 1-inch bars in the octagonal columns of the basement and two lower stories. These bars are hooped by a continuous spiral coil of $\frac{3}{8}$-inch wire ($\frac{1}{4}$-inch in the second story) having a pitch of $1\frac{1}{2}$ and $1\frac{3}{4}$ inch. The pitch is maintained by four vertical crimped wires placed on the outside and secured to vertical steel strips on the inside by clamps and set screws at every fifth space of the coil. With this arrangement the reinforcement of a column can be built up complete in the shops and dropped directly into place in the moulds. In the third and fourth floors, where the columns are square, the verticals follow its shape, eight in the third and four in the fourth story, and the hooping is horizontal 18 inches apart, the dimensions being also reduced.

C. O. B.

Steel Framework of the Tower of the Metropolitan Life Building, New York.

(Engineering Record, New York, 9 February, 1907, pp. 146-50.)

This is a fully illustrated article on the structural details of the steel skeleton of the tower of the Metropolitan Life Building, New York. There are thirty-two main-columns and fourteen secondary columns, twenty of which support and form a part of the 7,500-ton framework and are designed to receive the maximum column-loads, some of which are as high as $7\frac{1}{2}$ million lbs. The cast-steel pedestals on which these rest, and their bedding on the rock, are fully described, as well as the steel columns and bracing up to the forty-sixth story at the top. The wind-pressure is assumed as 30 lbs. per square foot of surface, and the method by which this is resisted is exhaustively treated. The total stresses in the corner-columns reach a maximum of 7,500,000 lbs., for which a cross-section of 540 square inches is provided by twelve 8-inch by 8-inch by 1-inch angles and three thicknesses of flange- and web-plates, as shown in one of the illustrations. The construction of the floors is also explained.

C. O. B.

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Adding to Chimney-Stack without Shutting-down.

J. F. JACKSON.

(Engineering and Mining Journal, New York, 2 February, 1907, p. 237.)

Four years ago a 200-foot steel chimney-stack, said to have been the largest plate-stack in the country, was built for the Copper Queen Smelting Works at Douglas, Arizona. It was found necessary later to increase the height by 60 feet, and this extension has been successfully accomplished without stopping the works while the addition was being made. False work, or scaffolding, was built up around the stack and to the level of the top, and on this the new section, weighing about 40 tons, was put together clear of the stack. When completed, this new 60-foot section was slowly shifted into position over the stack by means of a Barrett and a track jack, stopping frequently to reduce the vibration in the false work. The old and the new section were then connected by outstanding angles, ample provision being made for wind-pressures. The smoke interfered with the operations of shifting at first; but when the new section covered one half the area of the old stack the gases passed freely into the new channel and no further difficulty was encountered.

G. G. A.

Straightening a 250-foot Chimney.

(Engineering Record, New York, 29 December, 1906, p. 727.)

This circular 20-foot internal-diameter brick chimney at Detroit, founded on a 50-foot by 50-foot concrete base on clay, settled 12 inches on one side, the south, about 6 inches more than the opposite. To check this and straighten the stack, concrete splayed footings, 10 feet wide at base, were added laterally on the north and south sides, connected with the original base by steel beams embedded in the former and penetrating slots cut in the latter. The additional base, 1,480 square feet, was made 970 square feet on the depressed side by carrying the footing partly round the east and west sides and 510 square feet on the other, so as to help restoration to the vertical. The slots were 2 feet 6 inches deep and high, and the beams 12 inches deep 6 feet long and 16 inches apart.

The concrete was very carefully laid in layers well rammed, and the stack has already made a slight recovery.

C. O. B.

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New Children's Hospital at Zurich.

(Schweizerische Bauzeitung, Zurich, vol. xlviii., p. 245. 20 Figs.)

This article describes the hospital in detail, but the present abstract is chiefly concerned with the engineering work. In 1874 the first part of the building was erected, and this old portion now forms one of the wings of the main building. There are several detached blocks in the grounds for diphtheria, scarlet fever, etc., and these blocks are not connected with the main building by covered ways. The main block consists of basement, ground-, first- and second-floors, and has 65 beds, so that with 40 beds in the original part, and those in the detached blocks, the total accommodation is sufficient for 136 patients and 22 nurses. The architect was, at first, Mr. Alec. Koch, but, owing to his illness, Messrs. Locher & Co. completed the work. Low-pressure hot water is used for heating in radiators, but as these are considered to dry the air too much a special moistening-apparatus is supplied in each ward under hygrometric control.

The operating-theatre has a special system of heating. The floor consists of thin slabs of terrazzo, laid over floor-channels, through which heating-pipes are carried, so that the floor itself is heated. Besides this, the full width of one of the external walls is recessed to a height of about 6 feet, and the back of the recess lined with cork, and rows of horizontal pipes of small diameter are fixed in the recess. The front is closed with a smooth cover, which is flush with the face of the wall, and through this cover the heat is given off into the room. No pipes are visible inside the theatre. Sterilized water is supplied from a Sulzer apparatus. In the basement are two low-pressure hot-water heating-boilers and two steam-boilers. The whole of the work was carried out by Messrs. Sulzer Bros. The windows are all of the casement type and double. The construction of the floors is different from British practice; rolled-steel joists placed at about 2 feet centres support arches of hollow bricks, and on these is laid sand, and over the sand a thin layer of concrete covered with terrazzo. The ceiling consists of metal lathing. fixed to the soffit of the joists, and plastered below, and the total depth of the floor is only 12·6 inches. The total cost per patient's bed was £313.

E. R. D.

Protection of Metal Structures against Rust. G. Denil.

(Annales des Travaux Publics de Belgique, Brussels, 1906, pp. 1012-1126.)

The Author, in the introduction, points out that the use of metals in large structures is daily becoming greater; but while engineers make themselves intimately acquainted with the properties and strength of the metals they use, the preservation of these

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structures is a branch of the subject much neglected. Having employed frequently during recent years sand-jets for the cleaning of structures, he has made very exhaustive experiments to determine the best conditions of working and to improve the system. He also considers it advisable to point out briefly the general principles of chemical cleaning processes employed concurrently with the sand-jet. The general principles and the leading machines are first described, including those of Mathewson-Tilghman, Warren, Guttmann, and Newhouse and Schaffer. The Author then deals with the speed of the air at the jet; the law of the flow of compressed-air by tuyeres into the atmosphere; the work done by the projection of the sand; the relative practical density of the "air-sand" jet; the concentration of the sand at the orifice; and the dimensions of the jet. The speed of flow must not exceed 310 metres (1,016 feet) per second, any increase of pressure only causing the air to issue denser, and to expand incompletely. The sand and its preparation, the temperature of the jet, the heating of the sand and the conditions governing the use of hot sand are next referred to. The Author then deals with the effects of the sand-jet on various metals and stonework, and also the phenomenon of the luminescence of the sand-jet. Applications and examples of the installation of sand-jets are given, including various bridge work in the United States, the cleaning of the hulls of ships, and a portable workshop on the Central Belgian Canal. The Author next refers to the economic results of the use of sand-jets, with an analysis of the cost of the items comprised in their use, and the technical value of the sand-blast cleansing, with which, he points out, hand-cleaning cannot be compared, the latter only removing the outer crust of the rust, and failing entirely to reach into cavities. Chemical cleansing, including the various acid preparations, soda and fire, is next dealt with.

The Author then sums up the practical conclusions derived from this investigation. He considers that a system which, by an original and perfected means, allows the surfaces of metals to be stripped and the rust dislodged *in situ*, is far in advance of the inadequate paints with which structures are covered.

H. I. J.

Drying of New Buildings. A. Moreau.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, January, 1907, pp. 12–14.)

Certain difficulties caused by the use of open drying-stoves for new buildings, due to the fact that the moisture extracted by the heat in one part is often redeposited in another, are explained, and by reference to illustrations an account is given of the apparatus of Held, which is said to remove these objections. In the "Calor" stove a special generator of hot air is employed, and provision is made for a constant flow of heated air. The furnace-chamber

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contains three grates, one of which is horizontal and the two others vertical, composed of upright hollow iron tubes open at both ends. The fuel used is coke, and the supply of air is drawn from outside the dwelling. It is made to pass in at the base of the furnace and becomes heated in its upward passage through the hollow bars. The hot air circulates through the apartment and is removed by the aid of lateral hoods placed outside the tubes. It is then conducted by a temporary chimney to the exterior of the building, either by means of an existing flue or through a window. It is asserted that one of these stoves will thoroughly extract the moisture from a newly-built room in 48 hours, and will dry a new building more completely than would be possible in several months of ordinary atmospheric drying. It is stated that arrangements have been made to supply these stoves on hire.

G. R. R.

Dry-Rot Fungus. RICHARD FALCK.

(Zeitschrift für Hygiene, Leipzig, vol. iv, pt. 3, pp. 478–505.)

It is pointed out that the chief object of the present inquiry was to ascertain whether the fungus found in dwellings, the so-called *Merulius lacrymans*, is a specific disease peculiar to woodwork in houses, or is a widely-distributed growth in native timber. The views of experts who have written on this subject are quoted. The Author began by the search for the *Merulius* in the forests, where he ascertained it was widely prevalent, but was liable to be overlooked owing to the fact that it fructifies only in the late autumn and in winter. He found it in a hedge in the vicinity of Breslau, and it is very abundant in the local timber-yards, where it grows freely under the wood-stacks in the sawdust and chips. He likewise discovered it on living fir-trees and deep down in the moss below the surface of the ground at the roots. As the result of these investigations he was able to demonstrate that the house fungus is an entirely distinct species from those found in the open woods or out of doors on timber, and it has certain marked peculiarities which entitle it to rank as a separate variety. In order to indicate the distinction the Author proposes the name of *Merulius silvester* for the outdoor and of *Merulius domesticus* for the indoor species. Certain features in the mode of growth of the fungi which destroy timber are examined, and it is shown that the rate of growth differs very materially in the case of the chief varieties to which attention has been mainly devoted. Thus, at the same temperature, 22° C., the *Merulius silvester* grows about 2½ centimetres in four days, while the *Tomentella* grows 4·4 centimetres, and this rate of growth furnishes a ready means of distinguishing between certain of the fungi. The range of temperature which the various fungi can withstand divides the species

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which infest timber into three groups: those which cease to grow at 26° C., those which can resist 34° and those which can stand 40° C. The Author states that he has been able to prove that warmth is fatal to the growth of the dry-rot, and that in houses attacked by this fungus it is possible to destroy it entirely by heating the air to 38° C. for 4 hours, or a temperature of 40° will destroy its vitality in 60 minutes. On the other hand the *Lenzites* group of fungi are capable of resisting relatively high temperatures to an extraordinary degree.

G. R. R.

Truckee-Carson Project of the United States Reclamation Service.

W. P. Hardesty.

(Engineering News, New York, 18 October, 1906, pp. 391-401.)

The territory included in this irrigation project is situated in Western Nevada, the major portion of the water being derived from the drainage-basin of the Truckee River, whilst the land to be irrigated is mostly in the basin of the Carson River. The average annual rainfall over most of the latter territory is 5 to 6 inches; the climate is mild, and the conditions are favourable for raising by irrigation the ordinary crops of the temperate zone. The ultimate object is to irrigate about 350,000 acres of land, but the immediate object is to develop about 200,000 acres in the Carson Sink Valley. The irrigation system so far constructed consists of:—(1) the Truckee Canal for diverting the waters of the Truckee River from its lower canyon through the low watershed to the Carson River; (2) the diversion of the united waters of the Truckee and Carson from the Carson River by the main distributing-canal on to the principal areas of land in the Carson Sink Valley; (3) the lateral distributing-system for the further distribution of water to the land to be irrigated. The Truckee Canal is designed for the conveyance of about 1,200 cubic feet of water per second; its length is 30·9 miles. The head-works consist of a diversion-dam across the river, and the intake to the canal is placed at right angles to it. The dam, like the intake, is designed for the passage of water through it. It is 155 feet long, and contains sixteen regulating sluices 5 feet in width. The structure is mainly of concrete; the foundation, 171 feet long and 30 feet wide, is carried to an average depth of 4 feet below the bed of the river, a row of interlocked steel-sheet piling, 12 feet long, being driven in the bottom of the trench near the up-stream face. The tops of the piles project into the concrete, which was further strengthened by a grillage of steel rails. An apron of heavy stone, 5 feet to 2 feet thick, extends for 30 feet below the dam. The sluices consist of a lower and upper sluice, each 5 feet in height, with stop planks extending for 5 feet above the upper sluice. The lifting-mechanism raises first the lower

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sluice, until it reaches a horizontal flange projecting from the top of the upper sluice, when they are lifted together. The canal-intake is provided with nine sluices 5 feet wide, and arranged as in the case of the dam. The dimensions and inclination of the canal are adjusted to give a velocity of 3 feet per second with the full depth of 13 feet of water. A very common cross-section is 20 feet wide at the base, with side slopes of 1 or 1½ to 1 with an inclination of 1 in 6,500, but with less firm material the side slopes were flattened. The embankment has a top width of 8 feet, its height being 2 feet above water-level. The canal is lined in places with 6 inches of concrete—in rock excavations to reduce the width necessary by giving a smooth surface, and in soft ground in places where leakage would have serious consequences. There are several short tunnels on the line of which the finished width at the springing level is 12 feet; the altered sections merging into one another by gradual curves. Suitable waste-weirs and sluices are provided. Pending the construction of the lower Carson reservoir a temporary wooden flume discharges the water into the Carson River. The main distributing-canals divert the commingled waters of the Truckee and Carson Rivers from the latter river on to the land to be irrigated. These canals are led on both sides of the river, a dam being constructed across the river and intakes provided, very much as in the case of the Truckee River. The supply to the laterals from the distributing-canals is regulated by stop-planks. A system of drainage from the irrigated land is provided.

A. W. B.

Rectification of the Rhine Channel at Diepoldsau.

(Schweizerische Bauzeitung, Zürich, vol. xlix, pp. 7, 17, 34. 40 Figs.)

This article is a discussion of the report of the chief engineer, Mr. J. Wey, on the proposed Diepoldsau cutting in Switzerland to effect a rectification of the Rhine channel. In the report the Author first describes the means to be used in carrying out the intentions of the agreement made between the Governments of Switzerland and Austria, and then enquires whether the bed of the Rhine could not itself be deepened in a more suitable manner.

Reference was made in the *Schweizerische Bauzeitung* [1] to a "History of the Regulation of the Rhine," by the same Author, and from that work it appears that from the Lake of Constance to the town of Bauern there was a brisk traffic of vessels in the seventeenth century. Since that date the bed of the river has risen about 13·12 feet, and the best proof is the constantly increasing number of floods caused by the Rhine. In 1848 the river burst its banks thirty times. The chief causes seem to be the deforestation of the drainage-area and

[1] Vol. xv, p. 19.

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bad methods of regulating the river. The proposed remedies are afforestation, prevention of the passage of detritus from small streams, adding embankments, and the Diepoldsau cutting. During the floods of 1868 and 1871, it was found that high-water level was from 16·4 feet to 19·7 feet above low-water level. Sections of the valley show clearly that the Rhine now runs along a ridge, and since 1848 the bed has risen 6·56 feet near Buchs. Already two canals have been made, but they are insufficient. In 1892 it was agreed that the Fussach cutting should be made into the lake and completed in 6 years, and that the Diepoldsau cutting should be finished in 11 years, and these two works are illustrated by a number of views. The cross-section of the cuttings shows a central channel 131 yards wide by 11·48 feet deep, to take the normal flow, and at a distance of 76 yards back from each edge of this cutting a dam is constructed with its crown 26·24 feet above the bed of the cutting. The distance between the inside edges of the dams is therefore 283·4 yards, which is the maximum width available for floods. The Fussach canal cost about 50 per cent. more than was estimated; the extra being about £360,000, the bulk of which was due to reinstatement of the dams where they had sunk. In view of this it was decided to construct short experimental lengths of the Diepoldsau dams in the peat district and to observe results. A short length was constructed in October, 1900, and in July, 1901 it was found that the mass sunk into the soft ground was 165 to 207·5 per cent. of that which still remained above ground-level. The banks of the cutting had to be protected with thick layers of gravel, and all along the inner toe fascines were laid in large numbers and then loaded with masonry. The Author foresees great difficulties in the construction of the Diepoldsau cutting, and advises that it would be preferable to deepen the existing channel of the river, although it is very tortuous.

E. R. D.

Panama Canal Work. FULLERTON L. WALDO.

(Engineering Magazine, New York and London, February, 1907, pp. 703–16.)

This is a statement of the progress of the work up to the end of 1906, and a description of some of the heavier plant, and the condition of the workmen. 1,500,000 cubic yards of excavation is the record for the year, of which 875,000 cubic yards were taken out in August, September and October, the rainy season. The sixty-three steam-shovels at work include 40-ton, 70-ton, and the great 95-ton Bucyrus—the largest digging-tool in existence. The cost of excavation and haul, excluding general charges, is stated to be 72 to 93 cents (3*s.* to 3*s.* 10½*d.*) per cubic yard. In connection with this, there is at work a shifting-device which in 29 minutes throws 200 feet of line 3 feet 4 inches with seventeen operations. The Gatun dam and the great Culebra cut are generally described, and

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mention is made of the 500 borings on the site of the former, including 200 on the lock site, there being one boring for every 200 feet square. The character and social pursuits of the workers, and the extensive provision for their control, hospitals, food and recreation, are fully explained.

C. O. B.

Sea-Coast Protection with Reinforced Concrete.[1] H. Huisman.

(Ingeniøren, Copenhagen, 1907, pp. 25–9.)

The plan devised and carried out by the Dutch engineer, Mr. de Muralt, is of interest to a country like Denmark, which has such a great length of coast-line in proportion to its area. Reinforced concrete is employed for five distinct purposes:—(1) Protection of the top slope of a sea-dyke, and (2) of the bottom slope; (3) pitching of a steep beach or a down; (4) protection of coast and beach by moles and groins; (5) heightening of dikes. For all these works the concrete is strengthened with wire netting or Monier iron bars. The methods are well illustrated by numerous diagrams and photographs.

(1) and (2). For the first two purposes the ground is dressed to the slope intended, and is pegged with plugs or stumps 1 foot apart, driven down to within an inch or two above the ground. A bed of concrete is then laid flush with the tops of the pegs, and on them is spread the wire netting, which is thus adjusted to its proper position in the thickness of the concrete. The bed is rammed by means of a stamp small enough to pass through the meshes of the wire netting. The work is done in panels measuring 6 feet in horizontal width by 8 feet on the slope. Along each sloping side of a panel is laid a temporary beam, notched in steps, across which are placed boards to regulate the thickness of the upper layer of concrete, which is then spread upon the wire-netting, and thus forms a series of steps or ledges, all having their upper surfaces or treads sloping uniformly towards the sea. Between the panels a trench is excavated to a depth of 20 inches, which is rammed full of concrete armoured with wire netting or bars, so as to form strengthening ribs, both horizontal and sloping, for the panels on either side. On slopes the success of the method depends on the principle of subdividing the work into panels, each independent of the rest, which are held fast by the intervening ribs. Flanges moulded along the upper edges of the ribs project over the panels, and hold them down. The ribs thus form frames, which gives regularity to the whole work. The timbers are served with oil, in order to get sharp edges for the concrete and to prevent it from clinging to them. For an area of 100 square metres (120 square yards) at the top of a slope—using a mixture of

[1] See "Protection of Sea-Shores from Erosion," by Alfred Edward Carey, M. Inst. C.E.; Journal of the Society of Arts, 3 May 1907, p. 650.

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1 cement, 3 sand, 4 gravel—the quantities were 6,000 kilograms (118 cwts.) cement, 120 square metres (144 square yards) wire netting No. 9, 8 cubic metres (10 cubic yards) sand, 11 cubic metres (14 cubic yards) gravel, 20 days' labour. For the bottom of the slope, on which the sea acts, the mixture was 3 cement, 5 sand, 8 gravel, and ½ trass or lava; and the quantities were 5,000 kilograms (98 cwts.) cement, 115 square metres (137 square yards) wire netting No. 15, 9 cubic metres (12 cubic yards) sand, 10 cubic metres (13 cubic yards) gravel, 900 kilograms (18 cwts.) trass, 18 days' labour. The prices were 4·50 kroner per square metre for the top of the slope, and 5·25 for the bottom (4*s.* 3*d.* and 4*s.* 11*d.* per square yard.)

Already 30,000 square metres (36,000 square yards or 7·4 acres) of these slopes have been constructed in the Netherlands, mostly since March, 1906. The structure is cheaper than any other there employed, such as pitching with basalt or local stonework, which costs 7*s.* to 15*s.* per square yard. The reinforced concrete can be laid on any ground, and is more durable against storms, because water cannot get in beneath the slope. Experience has already shown that the most violent storms and highest tides, which on the coast of Zeeland have damaged slopes pitched with basalt, have left no trace on the adjacent slopes faced with armoured concrete. No repairs have yet been required, though they are needed constantly by the basalt slopes. The danger of any hollowing out at the foot of the apron is diminished by the horizontal ribs being sunk so deep in the ground; if any such hollowing did occur it would not involve the loss of a whole panel; nor can the slope roll over, as has happened with basalt pitching. Where exceptionally high tides scour earth away from dikes above high-water mark, the constant renewal necessary can be avoided by adopting armoured concrete, on which the outlay is speedily recouped by the absence of further cost for repairs. Where fresh water and sea-sand cannot be got, sea-water and dune-sand can be used successfully. Any ordinary labourers can do the work.

(3) For the foot of sea-banks or dunes reinforced concrete has proved the cheapest and most secure protection. Basalt pitching on a thick bed of clay, and covered with wattles and cuttings, requires on Schouwen Island (between the mouths of the Scheldt and the Meuse) an outlay of 11*s.* to 17*s.* per square yard; at the same place the reinforced concrete costs no more than 5*s.* 6*d.* In general it is sufficient to drive the piles 2 feet below the under surface of the concrete. The stepped face of concrete proves an admirable sand-collector. But the stepping is not indispensable; in some places a smooth slope without steps is preferable. Above high-water line No. 15 wire netting is sufficient, while for exposed situations No. 9 is used.

(4) For protecting coast and beach by moles and groins, the work is done in panels of minimum size, such that a panel or a rib can be completed between each flood-tide. The plan was first carried out on an existing mole of basalt, on the north side of Schouwen Island,

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which even in calm weather is exposed to strong currents. To do the work with basalt blocks of 2 feet height would have cost 40,000 marks (£2,000); with reinforced concrete it has cost no more than 15,000 marks (£750). The old basalt pitching, in blocks 1½ foot high, was removed piece-meal; and the uniform stepping of the concrete was secured by means of a timber template. Groins are protected in the same way as sea-banks or dunes.

(5) For heightening a sea-dike by means of a wall along the top the wire netting is bent upwards from the slope, within the thickness of the concrete wall. The obtuse angle along the foot of the wall is thus strengthened; and the vertical netting prevents the wall from cracking. A. B.

Brussels as a Seaport. PIERRE DE MERIEL.

(La Nature, Paris, 22 December, 1906, pp. 58–9.)

As far back as 1560 Brussels had access to the Scheldt by means of a canal, which enabled vessels not exceeding 10·16 feet in draught and 23·78 feet in beam to reach the Belgian capital from the sea. Notwithstanding many projects for improving this canal, which starts from Brussels at the Leopold Bridge and serves as a prolongation of the Charleroi Canal, nothing has yet been done. The existing canal has a total length of 17·39 miles and communicates with the River Rupel (a tributary of the Scheldt) at Little Willebroeck. The depth is 10·48 feet and there are four locks, not counting the entrance-lock at the junction with the Rupel. This canal is now being converted into a waterway suitable for sea-going vessels of large tonnage, and the new canal is to be completed in 1908. The cost is estimated at £960,000, and the undertaking is being promoted by a Company, the shares in which are held by the State, the Province and the City of Brussels, and by all the Communes which will profit by the enterprise. The depth of the new canal will be 18 feet and the surface-width 59 feet, but when the traffic warrants enlargement it is proposed to increase the depth to 21·32 feet and the width to 65·6 feet. The sides of the canal are lined throughout with masonry, which will enable vessels to move at a considerable speed, and for the same object the curves have in no case a radius of less than 2,870 feet. The locks are adapted to receive vessels up to 374 feet in length. A large and commodious outer dock is being provided near Brussels, at Laeken, adjoining the Schaerbeek Station, and also an inner harbour, in close proximity to the mercantile districts at the Place Tour et Taxis. This inner harbour (intended for smaller vessels) will be 2,952 feet long by 393 feet wide by 18 feet deep. The railway communication with the new Port of Brussels will be excellent, and there will be a large range of wharves with warehouses and cranes for unloading. The course of the canal is indicated on a sketch plan.

G. R. R.

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Steam-Turbine Air-Compressor on the Rateau and Armengaud System. A. Barbezat.

(Schweizerische Bauzeitung, Zürich, vol. xlviii, p. 235. Figs.)

A special centrifugal air-compressor has been constructed by Messrs. Brown, Boveri and Co., of Baden, Switzerland, for the Société des Turbomoteurs à Combustion, of Paris, and has been tested at the Baden works. The design is based on theoretical data furnished by Professor Rateau, and the compressor is intended to supply air to a petrol turbine, the principle of which was described in the *Schweizerische Bauzeitung*.[1] The Author refers to early experiments with a single rotary compressor driven by a De Laval turbine, for which the commercial efficiency was found to be about 48 per cent., and then describes the improved form, which consists of a group of wheels and diffusers working in series. The theory is referred to and illustrated by diagrams, and then the actual machine is described. It consists of twenty elements divided into three groups, each group being in a separate case, each smaller than that preceding it, for the wheels diminish in size as the pressure increases. Each group has a water-jacketed case, so that the final temperature of the air is only 50° C. above that at the inlet. When driven at a speed of 4,250 revolutions per minute the compressor delivered 40 cubic feet of air per second under a pressure of 71 lbs. per square inch, and absorbed 400 brake-horse-power. The Author defines efficiency as the ratio of the work theoretically necessary to compress a given quantity of air to the required temperature and the brake-horse-power absorbed in doing this work. He then states that the efficiency of the first group of the compressor was 73 per cent., the second group 68 per cent., and the third group 70 per cent., so that the efficiency of the whole was about 70 per cent. The actual results obtained are tabulated in the original, and the Author compares the figures with those obtained by piston-compressors, and concludes that the rotary-series compressor has advantages over the piston-compressor comparable to those which the steam-turbine possesses over the piston type of steam-engine.

E. R. D.

Alcohol-Engines. Elihu Thomson.

(Electrical World, New York, 1907, vol. xlix, pp. 20-2.)

In the opening sections of this article the Author discusses briefly the development of the internal-combustion engine in recent years, especially in connection with the arrangements for governing where a wide variation of speed is required, as in the case of automobile-

[1] Vol. xliv, p. 100.

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engines. Where petrol is used, warming of the vaporizer or the entering air has only been resorted to in special cases, but the difficulty of obtaining grades of petrol of the lowest boiling-points, together with the variation in effect when the outside temperature is low, is tending to compel attention to the need of a warmed vaporizer. If the fuel in the vaporizer is of higher boiling-point the vaporization is made effective by simply raising the temperature of the vaporizer or of the fuel as it enters the air with which it is mixed; or the temperature of the air may be raised, as well as that of the fuel. With an arrangement of this kind, alcohol may be used instead of petrol, and the same type of vaporizer as that used with petrol satisfies the conditions, except that a preliminary heating is given to make the alcohol-vapour as volatile as petrol at ordinary temperatures. Some time must elapse before the conditions of manufacture, and arrangements for distribution, will enable alcohol to compete in price with petrol in densely populated districts, but in the more sparsely populated districts where petrol now commands an advanced price alcohol should soon become a competitor. In spite of the smaller heat-value of alcohol as compared with petrol, the efficiency of the engine may be increased when alcohol is used by increasing the compression. By this means, a greater extraction of energy is obtained on expansion, giving a cooler exhaust, and the cooler gas, which remains in the cylinder and is mixed with the new charge, reduces the probability of pre-ignition. An alcohol-engine can be run with the water boiling vigorously in its water-jacket—a condition which almost invariably leads to pre-ignition troubles with oil- or petrol-engines, unless the compression is kept low. The first development in the use of alcohol in engines will probably take place in farming districts, or remote places where the price of petrol is high. At first the engines may be used with mixtures of alcohol and petrol in varying percentages with a gradual increase in the percentage of alcohol as its price falls. The use of alcohol would greatly reduce the dangers which at present attach to ship-propulsion by internal-combustion engines using petrol or highly volatile hydro-carbons. The necessity for preliminary heating of the vaporizer is but a slight disadvantage, as this can be done in a very short time and in a very simple manner, and all possibility of interruption due to freezing is abolished. If experience should show that the products of the partial combustion of alcohol are acid or corrosive for such a metal as iron, that result would only take place when the engine is out of action, or resting between runs, and could be neutralized by suitable means at the time of a shut down for a more or less prolonged period.

W. C. H.

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Novel Blowing-Engine.

(American Machinist, New York, 23 February, 1907, pp. 163–7.)

This is a fairly complete description, illustrated by photographic reproductions and sections giving full details, of a large blowing-engine, to which a new positive valve-motion, providing extra large valve-areas, has been applied. In the case of air-compressors ordinary care will ensure that the loss due to the suction- and outlet-valves is unimportant; with blowing-engines, however, the pressure is very low, and the valve-loss becomes serious. Thus, if the compression-pressure is 80 lbs. per square inch, a suction-drop of ½ lb. per square inch would represent 1·43 per cent. loss, whereas if the pressure were only 5 lbs. per square inch, the same suction-drop of ½ lb. represents 11·1 per cent. loss. The friction-loss of driving the machine itself is also far more important with low than with high pressures. In the blowing-engine described special attention has been paid to both these points, resulting in a somewhat novel construction. The valves are of the to-and-fro rotating-grid type, concentric with the cylinder, and housed in annular chambers round each end of the cylinder, communicating with annular ports also extending around the whole circumference of the cylinder. The valves are driven by eccentric rods actuating double wrist-plates, so disposed as to get a much longer pause than usual. This is the novel positive valve-motion mentioned above, and the effect is to greatly increase the effective valve-area, as is fully described in the article by means of a diagram. The valve-area is no less than 40 per cent. of the piston-area. The piston is built up of thin steel plates and is so designed that the junk-rings can be got at easily. The piston-rod consists of a thin steel tube, which although light is very stiff; it is carried by slippers at both ends. An indicator-diagram is given, of which the mean effective pressure is 2·02 lbs. per square inch. The suction shows no loss, although the scale of the diagram is such that 1 oz. per square inch is represented by $\frac{1}{32}$nd of an inch. The discharge-line has the usual undulations caused by the inertia due to the air surging through the receiver and the pipe-line, and the extreme rise above the receiver-pressure (2·02 lbs. per square inch) is about ½ lb. per square inch. The engine runs at 78 revolutions per minute. No records of tests are given.

H. R. S.

Grönkvist Drill-Chuck. Filip Langlet.

(Teknisk Tidskrift, Stockholm, 1906, Mech. and Elec. section, pp. 173–4.)

In a Paper read to the Mechanical Section of the Swedish Technical Association, the Author describes some half-dozen of the drill-chucks hitherto in general use. These involve the inconvenience of having to stop the drilling-machine in order to change the drill; and the

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latter is not held tight enough to prevent it from slipping under increased pressure. Moreover, certain component parts, such as the gripping-nuts and their threads, and the drill-shank, are subject to great wear and soon become useless; often they are so difficult to replace that a new chuck is needed. Recently, these objections have been met in an improved arrangement, devised by Grönkvist Brothers, of Katrineholm, in which the drill-shank is gripped between three small cylindrical rollers, working in slightly eccentric grooves, chambered in the casing which surrounds them. The plan may be described as a modification of a form of friction-clutch, in frequent use for driving machinery. The new chucks, as first made, were still subject to slipping, because the roller-grooves, though eccentric, were circular arcs; they are now shaped accurately to a logarithmic spiral, whereby all slipping is obviated. By turning the chuck to the right, or in the direction of running, the grip is tightened by hand while working; by braking its rotation by hand, or turning it in the contrary direction, the drill is released, but is just held by a pin or cotter from dropping out of its socket in the chuck. The chucks are made in five or more sizes, for drilling holes $\frac{1}{32}$ to $\frac{3}{4}$ inch in diameter. The Paper is illustrated by 16 photographs, of which 9 pertain to the previous chucks, and 7 to the Grönkvist. The chuck is also being manufactured in America.

A. B.

Apparatus for Conveying and Piling Timber.

(The Engineer, London, 18 January, 1907, pp. 68–9.)

A special type of conveyer has been constructed by Messrs. Wintringham and Son, at their timber-yard in Grimsby, for rapidly unloading sawn timber. The transporter runs on rails and can be moved along the quay-side to suit the position of the ship to be unloaded. The rails are laid parallel to the edge of the wharf and the conveyer is at right angles to it. Only one hatchway can be emptied at once with one conveyer, but the timber can be conveyed to any reasonable distance, and practically any sizes of sawn timber, except short lengths, can be dealt with. The structure consists essentially of substantial timber towers mounted on double flanged wheels which run on the rails. At the top of each tower there is a cross-beam which carries four pulleys supported by strong bearings. The ropes for lowering or raising the conveyer pass over these pulleys to the drums of the winches or other winding-gear. The transporter is built up in sections, consisting of a number of steel girders which form a floating platform which can be raised or lowered in the manner just described, to suit the height of the stacks. There are three lines on the transporter, placed side by side. At intervals of about 4 feet there are massive bearings carrying the rollers. These are operated by gearing from a single shaft running the length of the conveyer and receiving its motion from an electric motor. When

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the deals reach the point where it is desired to stack them, they are diverted from their forward course by special rollers which can be inclined to the longitudinal axis of the line, to deliver the timber to either side. These diverting-rollers are mounted on short shafts, connected by universal joints to the central cross-shaft mounted in fixed bearings in the central line, and driven by helical gear from the main shaft. An outrigger is placed at the sides of the line to break the force of the fall of the timber, and to support the platform for the attendants who control the rollers for discharging the timber. The front section of the conveyer is designed to swing in the vertical plane, so that it can be adjusted to suit the heights of the hatchways and the transporter.

A. W. B.

150-*ton Dock-Crane with Derricking-Jib.* A. C.

(Le Génie Civil, Paris, vol. l, pp. 153-5.)

A dock-crane of somewhat unusual type has recently been erected at Tsing-tao; it consists of a lattice tripod firmly embedded in the ground. The crane-post passes through the centre of the stage surmounting this tripod and is extended down to the ground-level where it is supported by a footstep. Attached to the top of the crane-post is the platform carrying the machinery, balance-weights and jib. The latter is a framed structure composed of a pair of struts to form the jib proper and a similar pair of members to form the back-stays, both jib and back-stay being connected together by diagonal bracings. The jib thus built up is mounted on a horizontal axis and a derricking motion can be imparted to it through the intermediary of two similar screws working in nuts, one at the lower end of each of the girders forming the back-stay.

The crane is electrically-driven throughout, four motors in all being used, one for lifting, one for derricking and two for slewing. The lifting-motor, which is of 110 HP., is used either for the light or the heavy purchase, and interlocking brake-arrangements are provided, so that when either purchase is to be disconnected from the motor this cannot be effected until the main drum of the purchase is efficiently braked. The derricking-motor is of 57 HP. and it is coupled to the two screws by bevel-gearing. As regards the slewing, the two motors act on opposite sides of a circular rack and are each of 12 HP. Of the two purchases the light one occupying, as usual, the outer position on the jib, is capable of lifting 50 tons, while the heavy purchase can deal with three times this load.

The respective speeds of lift are 6·30 metres (20·66 feet) and 1·73 metre (5·67 feet) per minute. Power is supplied at a pressure of 500 volts and slip-rings are provided on the lower end of the crane-post for the purpose of coupling-up, four brushes being in contact with each ring.

I. C. B.

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40-ton Hydraulic Coal-Hoist.

(The Engineer, London, 4 January, 1906, p. 21.)

A 40-ton hydraulic coal-hoist has been erected at the new docks at Middlesbrough, which has been arranged so that it can accommodate with equal facility and without loss of power wagons of 10 to 40 tons capacity. The hoist consists of a large cradle, about 29 feet by 19 feet, into which a hopper capable of containing 40 tons of coal is built, which moves in a massive steel framing and has a range of lift of 85 feet. The cradle is lifted by four wire-ropes attached to the corners, carried over conveyance-sheaves on the top of the framing to two hydraulic cylinders, with rams working downwards, placed on the back of the framing; the rams are solid to counterweight the cradle. The front of the framing is fitted with a shoot, which can be adjusted and fixed at any height up to a maximum of 55 feet above the water level. The wagons are run on to the cradle, their bottom doors opened to discharge their contents into the hopper, and run off again; the cradle and hopper are then raised to the necessary height to suit the shoot. The hopper is provided with a door on the shoot side, through which the contents are discharged when the door is opened; by turning it down it forms a connection between the hopper and shoot. The opening and closing of the door is effected from the cradle by hydraulic cylinders. The hoist when fully loaded can make the lift of 85 feet in one minute, and on the average 400 tons of coals per hour can be shipped by it.

A. W. B.

Suction-Gas Apparatus with Peat-Fuel. C. E. L. Hubendick.

(Teknisk Tidskrift, Stockholm, 1906, Chemical and Mining section, pp. 131-5.)

An illustrated review traces the development of the gas-engine from the original four-cycle Otto of 1876, followed in 1881 by the Dowson gas-producer. Detailed descriptions are given of the latter and of the arrangements devised about 1894 by Bénier, and later by Taylor, for using anthracite-coal. In 1900–1 their attempts were taken up by Pintsch in Berlin, with an apparatus of 75 HP. Other makers, including Körting in Hannover, then entered the field; and in Sweden a number of suction-gas works were speedily in operation. Among these are the electricity works at Nyköping of 100 HP., at Upsala of 530 HP., and at Seffle of 90 HP. which will shortly be augmented to 180 HP. Here the consumption of anthracite at full load or 89·1 HP. effective was 0·82 lb. per HP. per hour; and at half load or 46·9 HP. it was

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1·24 lb. So far only non-bituminous fuel could be used, such as anthracite or coke or charcoal; which are so expensive that endeavours were made to contrive apparatus for employing bituminous coal, lignite, peat, and wood. One of the first to succeed was the Mond generator, in which bituminous coal is gasified with the addition of an ample supply of steam. The result is gas so free from tar that it can be used direct in gas-engines; but the great quantity of steam required renders the firing troublesome and the efficiency poor. In order that the process may pay, care must be taken of the nitrogen which forms ammonium sulphate; and the apparatus for utilizing the by-products does not pay for treating less than 20 to 40 tons of bituminous coal per day. The annular generator by Jahns of Saarbrücken likewise gives gas entirely free from tar; but its composition varies greatly, and its efficiency is about 50 per cent. Lignite does better.

The extent of the peat-bogs of Sweden is estimated at 10 to 12 per cent. of the entire surface of the country, and the store of fuel therein would supply present requirements for a thousand years. If therefore peat were employed for large industries, the enormous outlay for coal might be largely diminished. Hitherto the difficulty has been that a dry summer could spoil the whole production of peat-fuel for that year; and drier bog will no longer yield generator-gas free from tar. A certain quantity of water in the fuel is a benefit. Suction-gas generators for peat have been put up during the past 2½ years by Körting; and on trial of peat containing 27 to 28 per cent. water and 6 per cent. ash, with a heating-power not exceeding 3,200 calories (5,760 B.Th.U.), the gases evolved were:—carbonic acid 11·4 per cent., carbonic oxide 16·8 per cent., hydrogen 8·3 per cent., light carburetted hydrogen 4·8, and nitrogen 58·7 per cent. In four trials the efficiency of the generator averaged 74½ per cent.

Dry peat has been gasified in Pintsch suction-gas generators by mixing with it about 50 per cent. coke, and has yielded the following gases:—carbonic acid 10 per cent., carbonic oxide 23, hydrogen 12, light carburetted hydrogen 0·6, and nitrogen 54·4 per cent. A peat-gas generator by Luther of Brunswick has been put up in Sweden, which requires the crushed peat to be riddled before it is fed into the generator; and the quantity of refuse so separated is astonishing. Briquetting is too dear to be adopted.

For motors, peat underwent a four days' trial with a Körting generator at Skabersjö near Malmö, when with ordinary running the consumption of peat was 4½ per cent. below that guaranteed, although the new gas-engine of 160 HP. had not been kept running more than a couple of days beforehand. A trial of a motor which has been running 2½ years in Burängsberg mining district gave 66·9 HP. on the brake, and 82·3 HP. by indicator, with a consumption of 2·46 lbs. of peat per effective HP. per hour. The peat contained 39·71 per cent. moisture, 4·38 ash, and

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54·91 per cent. combustible material, yielding 2,689 calories (4,900 B.Th.U.), equivalent to 5,141 calories (9,200 B.Th.U.) from dry peat. The mechanical efficiency of the motor was 81·3 per cent., and the heat used was 3,012 calories (5,400 B.Th.U.) per HP.-hour. In a trial of two months' continuous working the total time of firing was 1,464 hours; the motor ran 1,080 hours and stood idle 384 hours. The total consumption of peat was 108,000 lbs., of which about 25 per cent. was water. While the motor was idle the consumption was about 8·8 lbs. per hour, or 3,300 lbs. for the whole time of standing. The effective load was 45 HP. The consumption per HP.-hour was therefore 2·15 lbs.; and taking the peat to contain 25 per cent. water, its useful heating power is 3,600 calories (6,500 B.Th.U.) The efficiency of the generator works out at 72½ per cent. under a fluctuating load, which averaged 75 per cent. of the maximum load. The generator has proved easy to mind, the motor runs steadily and well, and is accurately controlled by its governor. After two years' running the consumption is 2·18 lbs. of peat per HP.-hour, showing that the whole is working as economically as at starting. The gas-motor works at Skabersjö are the first in Sweden where the three-phase generators, producing current of 3,000 volts, work in parallel.

As a vacuum prevails in the suction-gas apparatus and its connections, it is free from leakage of gas outwards; and though leakage of air inwards may occur, this could not fail to be observed long before it was enough to form an explosive mixture. While there are still many important problems to be solved in the use of bituminous fuels, it is clear that suction-gas works in connection with gas-motors are now among the safest and most economical arrangements to be met with.

A. B.

Suction-Gas Machinery for Vessels.[1] GUSTAV SETH.

(Teknisk Tidskrift, Stockholm, 1907, Shipbuilding section, pp. 8–18.)

In an elaborate Paper to the Swedish Technical Society, the advantages were pointed out which suction-gas offers in comparison with pressure-gas for driving propeller-machinery on shipboard. In order that the generation of gas may proceed favourably, it is requisite that the air and steam should come in contact with as large a surface as possible of the fuel in proportion to its volume, and that scaffolding and fissuring of the charge should be avoided, as well as caking of the fuel and excess of slag. In all these respects, anthracite crushed small offers the greatest advantages,

[1] See Minutes of Proceedings Inst. C.E., 1906, vol. clxvii, pp. 432 and 433.

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especially for small vessels, and for short trips in which there is no need to replenish fuel at foreign ports. But as anthracite is not to be had at all ports, and its cost is so great, measures must be taken for burning bituminous coal with equally good result. Here is the most important field for ingenuity in the employment of internal-combustion motors for the propulsion of vessels. On land, power-gas is successfully generated from bituminous coal; and the Author has heard that a plan is being studied for vessels by Messrs. William Beardmore and Co., Glasgow. In a generator arranged by the German engineer, Mr. Emil Capitaine, the fresh coal is fed in at the bottom by under-feed stoking, whereby it is supplied at once to the hottest region, so that the hydro-carbon gases are burned immediately on being given off. From the generator the gas usually passes through a purifier filled with coke or sawdust; but on shipboard a scrubber with water-spray saves room and purifies the gas sufficiently, at the same time cooling it. The water is separated from it by a high-speed centrifugal, and if necessary by further passing the gas through a vessel fitted with a number of baffle-plates which collect any remaining moisture. For starting the generator, air under pressure is blown in by a fan worked by hand, and the poorer gas at first generated is discharged; as soon as the quality is good enough, the discharge-valve is reversed and the richer gas goes into the motor, along with the air sucked in by the fan. A complete suction-gas apparatus therefore comprises generator, purifier and blowing-fan, together with the motor itself. The last can be either single-acting or double-acting, and either two-cycle or preferably four-cycle. A single-cylinder single-acting motor requires a heavy fly-wheel to equalize the intermittent power.

The first attempt at driving a propeller by suction-gas was made in 1902 at the Deutz Gas-Motor Works, where a cargo-boat was equipped with suction-gas machinery of 30 HP. to ply on the Rhine and on the Dutch and French Canals for Messrs. Haldy Brothers of Saarbrücken. Its success was quickly followed by the *Lotte* of 100 HP. and 240 tons. Both are of German canal-boat build, long, narrow, shallow, with plated sides and wood bottom. The *Haldy* has a single-cylinder motor lying horizontally and longitudinally, driving the propeller-shaft through complicated gearing. The inner end of the shaft is hinged in order to allow of raising or lowering the outer end, on account of the shallow draught when empty. The generator is placed in the forward compartment of the engine-room on the port side, and the purifier abreast on the starboard. Abaft lies the silencer for the exhaust gases, and on the starboard side a compressed-air receiver for starting the motor. The *Lotte* has two horizontal double-cylinder motors lying athwartship on either side of the longitudinal driving-shaft. The generator and purifier occupy a separate compartment ahead, which prevents any gases from penetrating into the engine-room during blowing and also protects the motors from soot and heat during slagging. The

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propeller-shaft is driven from the motor-shaft through a friction-coupling. The propeller-blades can be slewed to different angles for altering the speed and direction of the vessel's motion.

The principle on which the Capitaine suction-gas machinery has been so extensively constructed during the past five-and-twenty years is that for vessels it must be as distinct from that for stationary use as is a marine steam-engine from one on land. Steel framing with angle-bars, instead of cast-iron, has enabled the total weight of machinery to be reduced to less than one-half, with lighter fly-wheel for equally steady running; cast-iron is retained only for the cylinders and their covers, and for the plummer-blocks. In an 80-HP. yacht built in 1905 by Messrs. John I. Thornycroft and Co. the steel frame is riveted direct to the body of the vessel, which is thereby strengthened, while also made 15 per cent. lighter than it would be for a marine steam-engine with surface-condenser. The cylinder being vertical, the top cover containing the valves is slid into place horizontally underneath fillets in the frame, by which it is held down upon the cylinder; it can be slid out to one side whenever the cylinder or valves want cleaning. In a multi-cylinder engine the cleaning of any one cylinder can be done in a few minutes, without interrupting the motion of its own piston or the working of the other cylinders. A damper controlled by the governor regulates the quantity admitted of the constant mixture of air and gas.

Gas-motors have the disadvantage that they cannot be reversed, but require complicated mechanism for going astern. Messrs. Beardmore are said to have in hand a reversible motor of 600 HP. Another defect of gas-engines is the quick revolution necessary to give the high piston-speed requisite for securing the least possible cooling of the cylinder. One Capitaine motor of 80 HP. makes 250 revolutions per minute, while another of 600 HP. makes only 150.

Mr. N. G. Nilsson considers that suction-gas machinery has so far made its way only into small fishing-, coasting- and pleasure-vessels. A fleet of cargo motor-boats has appeared in Sweden, all driven by petroleum motors; the largest is believed to be the *Ursus* motor-lighter of 250 tons, recently built at Bergsund for Finland. The Stockholm Transport and Towing Company has procured five new motor-boats of only about 85 tons, which have to be small enough to pass through the locks and canals north of Lake Mälar. The German motor-works of Daimler and Co. have furnished their motors for cargo-boats up to 470 tons capacity. Diesel motors are carried in two oil-boats of over 1,000 tons displacement and in a number of French submarines. All these motors labour under the disadvantage that, for going astern, they require mechanical arrangements of a more or less complicated nature. A Swedish engineer, Mr. A. Izakson, has devised a plan both for reducing speed and for going astern by means of a water-jet reaction apparatus.

Mr. C. A. Lindvall mentions an iron lighter built at Bergsund in 1906, driven by a petroleum-motor, having a speed of 6 knots and

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working round the whole Gulf of Finland. Solar oil, which is cheap, was found most serviceable. The gas was ignited not by electric spark, but by high compression. The engine ran reversed without difficulty, to the satisfaction both of the owner and of the engineer on board.

Mr. H. Lilliehöök recalled his experience of five spar-torpedo boats built many years ago, of which four were provided with ordinary propellers and tested up to a speed of 10 knots, while the fifth, having two centrifugal pumps discharging astern, did not exceed 8·12 knots. In the English gunboat *Viper* the reaction-jet had not given satisfactory results. The Reversator Company have brought out an explosion-motor which appears to have solved the problem of reversing for smaller engines and to hold out good hopes for larger.

Mr. J. Schmidt said the largest Reversator motor was one of 40 HP. with four cylinders in a boat with which 15 knots have been attained. Drawings are now being got out in Kiel for Reversator motors of 60 and 90 HP., and he sees nothing to hinder reaching still higher power.

Mr. A. Ljungman referred to unpleasant experience and even loss of life with stationary suction-gas apparatus through leakage of the generator-gas containing 26 per cent. of highly poisonous carbonic oxide. In a rough sea, when leakage of gas would be most likely to occur, it might be difficult to ventilate the engine-room satisfactorily.

Mr. H. Lilliehöök said the same danger arose with oil-gas and benzine; the pump-work must be utilized for clearing away any leakage of gas. In the French submarine boats the precaution was adopted of carrying small white rats, which were so sensitive to any such leakage that they gave warning of its occurrence by becoming stupefied. Internal-combustion motors should not be driven with volatile oils.

Mr. N. G. Nilsson understands that for a new fleet of fifty submarine boats, intended to be built for the French navy, it has been decided to abandon internal-combustion motors and revert to steam-engines.

Mr. Gustav Seth believes that gaseous fuel is safer than liquid, especially for higher power. In numerous trials of motors using liquid fuel he has found how easily the valves get stuck up or leaky through small solid particles of soot or rust in the oil. In a petroleum-motor up to 40 or 50 HP. the admission-valve for the oil is not more than a few hundredths of an inch in diameter; whereas a gas-engine of the same power has an inlet-valve of 2 inches diameter, which is considerably easier to keep in order. At present no Swedish motor burning petroleum or benzine has been so arranged that the valves and cylinders can be cleaned while running, as can be done with the Capitaine suction-gas motor. The distinction must be borne in mind between the motor being reversed and the boat going astern. The latter is effected either through gearing or through slewing the

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propeller-blades. The Reversator motor can be reversed instantly and without difficulty; but even with a small motor the reversal produces such a shock as with higher power would become risky for the boat, owing particularly to the momentum of the heavy flywheel. The only practical precaution is to shut off the gas at the moment of reversing, and admit compressed-air to work expansively like the steam in a steam-engine; the sudden shocks of the explosions are thus avoided. Owing to the vacuum always prevailing in the suction-gas apparatus, the danger of escaping gas through a leaky joint or a broken tube is reduced to nil. Even if air leaked in, no dangerous explosion could occur, as the quantity of gas in the generator is too small. The German East African line has despatched lighters with suction-gas motors between Germany and Africa, and a Capitaine arrangement of 600 HP. has recently been placed in the highest class of Lloyd's Register.

The Paper and discussion are well illustrated by six plates of drawings and three photographs.

A. B.

Pattern-making and Moulding of Air-cooled Gas-Engine Cylinders. E. F. Lake.

Air-cooled Gas-Engine Cylinder Construction. Hugh Dolnar.

(American Machinist, New York, 1907, 19 and 26 January, pp. 2–5 and 39–42.)

The first of these articles describes the air-cooled cylinders of automobile-engines and the somewhat complicated pattern-making and moulding required for them. It is stated that, whereas the water-cooled cylinder has been brought to practical success in Europe, the air-cooled cylinder is distinctly an American development, and that the system is being successfully employed in four-cylinder, four-cycle, 40-HP. engines. It is pointed out that radiation alone is insufficient to carry away the heat from the cylinder, and that convection must be employed as well by the use of a fan or a blower driven by the engine. Several of the methods adopted for increasing the cooling- or radiating-surface are described, such as numerous thin flanges or gills or "pins" cast with the cylinder or screwed into its walls; or again, metal combs inserted into grooves; the two latter arrangements giving the cylinder the appearance of a porcupine. Copper, brass, or aluminium gills have also been used. The Author then describes another method, in which the cylinders are air-jacketed with sheet metal and a current of air is forced through by means of a fan. One American manufacturer has so arranged this design that the

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cylinders can be either air-cooled or water-cooled. A somewhat remarkable engine is described, in which the cylinders revolve, and, since they are continually in contact with a fresh current of air, no fan is needed, nor is any fly-wheel required. Such engines are made with either three or five cylinders, and it appears that a considerable number have been placed on the market during the past 2 years. An interesting point is mentioned, viz., that when a fan is used in front of the engine it is the cylinder closest to the fan which is the hottest, the reason being that the tips of the fan-blades throw out the largest volume of air, and this strikes the rear cylinder. The article concludes with a description of the pattern-making and moulding of air-cooled cylinders sufficiently detailed to enable an experienced pattern-maker and moulder to carry out the work.

The second article deals with the same subject, describing in considerable detail the manufacture of the Corbin air-cooled cylinder, in which the cooling-surface is obtained by means of steel combs fixed in grooves. Several illustrations are given of the method adopted for machining these grooves, which requires no less than twenty operations. A fully-dimensioned section of a cylinder is also given. The full width of the steel comb is 1½ inch, and there are eighteen rows of them per cylinder. The total weight of a 4½-inch cylinder is 21 lbs. 4 oz.

H. R. S.

New Form of Speed-Indicator.

(Le Génie Civil, Paris, vol. xlix, pp. 313-4.)

Speed-indicators hitherto in use are of two kinds, the one depending for its action on centrifugal force, and the other on a direct count being made mechanically, from time to time, of the number of revolutions during a very short standard interval. The indicator under notice operates through a wholly different principle, viz., that of resonance. The instrument consists of a number of springs or blades of metal each free at one end and fixed rigidly at the other to a single bar capable of receiving impulses in the plane of vibration of the springs. These impulses are communicated either electrically or mechanically from the shaft, the velocity of which is to be determined. The vibratory period of each spring is different from each of its fellows. Should the period of the impulses derived from the rotating-shaft synchronize with that of any spring, the latter will be thrown into strong vibration, while the other springs will remain more or less quiescent. Opposite each spring can be marked the number of revolutions per minute of the shaft when the impulses synchronize with the particular spring. This is not necessarily the vibratory period of the spring, as more than one

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impulse per revolution of shaft is desirable, particularly when the rotation is slow. If two adjacent springs vibrate with equal amplitude it may be presumed that the speed of the shaft is midway between the figures represented by the respective springs, while if the amplitude of the one is greater than that of the other the speed lies between the two and will be nearer to that which is vibrating the more strongly. No mention is made of the behaviour of a spring when the impulses are either a measure or a multiple of its vibratory period.

I. C. B.

Reinforced-Concrete Machine-Shop Building.

(Railway and Engineering Review, Chicago, 6 October, 1906, pp. 773-4.)

The machine-shop of the the Taylor Wilson Manufacturing Company in McKees Rock, Pa., is 160 feet long by 102 feet wide, and consists of a centre aisle 51 feet 7 inches wide with two lean-tos 18 feet wide on one side, and 30 feet wide on the other. The centre aisle is arched over, and the roofs of the lean-tos are flat. The height from floor-level to soffit of arch is 50 feet 3 inches, and that of the lean-tos varies between 19 feet 3 inches at inside and 18 feet at outside row of columns. Two rows of circular columns 20 inches in diameter, spaced 20 feet apart centres, flank the centre aisle. These pillars support 18-inch circular columns which carry the crane-girders, and 12-inch by 12-inch square columns which pass through the upper flange of the crane-girders and support the roof of the centre aisle. The pillars also assist in supporting the roofs of the lean-tos. Two rows of columns 12 inches square support the roofs of the lean-tos on the outside and form the side walls of the shop.

The moulds for the circular columns were formed of 16-gauge galvanized iron. The column-reinforcement consists of four vertical rods to which are attached a series of hoops, $1\frac{1}{2}$ inch by $\frac{1}{8}$ inch, spaced 4 inches apart. Each hoop had a projecting fin which held it at the proper distance from the form. Where the column runs into the beam the area of column cross-section is increased. The crane-girders were designed to carry a 30-ton overhead travelling-crane. Each girder spans 20 feet and is 36 inches deep by 18 inches wide, and has also an upper flange on one side which serves to take up the side thrust caused by the cross traverse of the crane. The reinforcement consists of five bars $1\frac{1}{8}$-inch in diameter in both the upper and lower portions of the beam running continuously over the columns, together with six looped bars $\frac{3}{4}$ inch in diameter in the lower part of the beam. The looped bars are bent up at each end into the beam for a length of 4 feet, the horizontal portions varying in length between 7 and 14 feet. Each set of six serves therefore to resist the shearing-stresses in each span, the bars being arranged symmetrically about the centre. The upper flange is reinforced

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laterally by bars 2½ inches in diameter on the outer portion, together with bars 1 inch in diameter arranged as a double lattice across the top of the beam. The rods are supported by small spacers stamped from sheet metal. The main aisle is covered with a concrete arch, 4 inches thick at crown and 10 inches at haunches, span 54 feet. The steel reinforcement consists of rods $\frac{5}{8}$ inch in diameter spaced 9-inch centres, running across the arch. The rods are laced together by strips of band iron 1 inch by $\frac{1}{8}$ inch. The thrust of the arch is taken by tie-rods made up of two 3-inch by 2½-inch by $\frac{3}{16}$-inch angles, spaced 10 feet centres. These tie-rods are bolted to two 10-inch channels, 15 feet long, placed back to back at the springing of the arch. A light skew-casting rests in the upper channel and acts as a spacing-member for the roof-rods, and also serves to transfer the load to the tie-rods. Expansion-joints were made in the roof every 10 feet to avoid any internal stresses due to temperature changes. The side elevation is taken up almost entirely by windows. The cost of the building is stated to be approximately 3¼ cents (1⅝*d.*) per cubic foot. Two drawings and two photographs accompany the article. The proportions of the concrete are not given.

J. M. M.

Modern Foundations for Heavy Tools.

(American Machinist, New York, 23 March, 1907, pp. 314–5.)

The Norton Grinding Company, Worcester, Mass., have introduced a type of adjusting-plates for use in the foundations of heavy machine-tools of precision. These plates consist of a very stiff casting, into which is fitted a surface-plate, adjustable by means of wedges actuated by two horizontal opposing screws. Each foot of a planer, or other machine-tool, rests directly on one of these surface-plates. The concrete foundation is first filled to within 8 or 10 inches of the floor, and the adjusting-plates are then located in their proper positions, and are levelled and adjusted by means of four vertical screws. The concrete is then filled in around them up to the floor-level, leaving spaces, however, for the horizontal adjusting-screws; these openings are subsequently covered by means of cast-iron plates. The horizontal adjusting-screws enable the surface-plates to be adjusted and "trued" (within limits) after the machine-tool has been erected, or at any subsequent time, should the tool get out of truth, due to wear or to deformation of the concrete foundation. Such adjusting-plates undoubtedly form a costly foundation, but expense is saved in other directions, such as that of scraping the bed of the machine-tool. They are specially applicable to planing- and grinding-machines. An interesting feature is that it has been found unnecessary to bolt planers to the foundations. The practice is to drill into the plates and to put in a ½-inch pin at each side of one or more pairs of the feet of the planer to prevent sliding. The

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article is illustrated by three photographic reproductions showing one of the adjusting-plates, and also a number of them in position before and after filling up the concrete.

H. R. S.

Electric Power for Mine-Haulage. M. F. PELTIER.

(Engineering and Mining Journal, New York, 16 March, 1907, p. 528.)

In no direction has the application of electricity to mining been more successful than in the operation of underground haulage. The Author shows by actual results the superiority of this method over horse- or mule-haulage. In the mine with which he is associated the replacing of thirty-five mules by two electric locomotives resulted in an increase in the daily output of 600 tons of coal and in a saving of ½*d.* per ton in the cost of production, besides which the plant is estimated to pay for itself in 4 years. The two locomotives are of the 15-ton Goodman type, the frames of which consist of an upper and a lower casting, bolted together, and suspended from the wheel-axles. No part of this frame overhangs the rails—an important feature in narrow workings. The wheels have steel tires, which give them 20 per cent. more tractive power than the chilled rim. These locomotives are provided with two motors, wound for 250 volts, and are capable of exerting a draw-bar pull of 8,200 lbs. on the level. The trolley-pole is of the reversible type, and is designed to adjust itself to varying heights of roof. They have pulled seventeen loaded trucks, weighing over 72 tons, up a 2½-per-cent. gradient 400 yards in length. The gauge of the line is 42 inches and the total length is 3,000 yards. It is laid with 40-lb. rails, which are bonded and cross-bonded for return current. The curves are 40 to 60 feet in radius, which gives 16 to 18 feet from point of frog to point of switch on all cross-overs and turn-outs. The outer rail is raised to suit a speed of 8 or 10 miles per hour. The electrical power for the motors and for lighting the underground roads is obtained from a 175-kilowatt generator belted to a 200-HP. high-speed, 18-inch by 18-inch engine at surface. Some of the advantages of electric haulage are the simplicity of the installation, its flexibility and the low cost of maintenance. This plant, which has been working a year, has cost less than £20 for maintenance.

G. G. A.

Improved Electric Motors for Mining Use. H. M. WARREN.

(Engineering and Mining Journal, New York, 2 March, 1907, p. 433.)

In describing the electrical equipment of the Woodward Mines at Kingston, Penn.—a typical example of an isolated direct-current station—the Author directs attention to recent improvements in the

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design of motors for mining use adopted for the plant there installed. By using a series and parallel controller there results a considerable saving of power. Another advantage of this arrangement is that the rheostat does not become overheated and its life is thereby greatly prolonged. The electrical plant in the mine consists of ten locomotives, nine hoists and six pumps, the total rated power being 1,796 HP. Two types of locomotives are used, one weighing 13 tons and the other 6½ tons. The heavier one is provided with two 50-HP. (railway-rating) motors, controlled by a series and parallel controller. It is capable of developing a draw-bar pull of 4,500 lbs. at a speed of 7½ miles an hour, when the motors are run in multiple, and 5,200 lbs. for a short time with the rails sanded. When the motors are run in series, the speed is approximately 3·2 miles per hour at the rated draw-bar pull. These locomotives are used for long and heavy haulage on the main roads. The smaller type of locomotive is provided with two 25-HP. motors, and these are also controlled by a series and parallel controller. It is furnished with the usual automatic reel device, containing some 700 feet of cable, to be used when collecting or delivering trucks away from the trolley-wires. This locomotive will exert a draw-bar pull of 2,500 lbs. The speed with the motors in multiple is about 5 miles per hour at the rated draw-bar pull. With the motors in series the speed is 3·8 miles per hour. When the rails are sanded the momentary pull is 2,700 lbs. The use of a series and parallel controller effects a considerable saving of power, which would be lost otherwise in heating the rheostats when required to run at half-speed or less. The first gathering-locomotive of this type was installed in the Cayuga mine of the Lackawanna Company in 1902, where it was given a thorough trial. The results were so satisfactory that orders were placed for others, and this Company have now eighty of them at work. The same system of series and parallel is used for the hoists, for the varying loads of which it is particularly suitable. In changing from series to multiple in these the circuit is not entirely broken, but one motor momentarily carries the load to prevent too great a strain on the rope due to sudden change in speed.

G. G. A.

Electric Motors for Rail-Mills.

(Engineering and Mining Journal, New York, 24 November, 1906, p. 966.)

Some very large electric motors are being built for the Indiana Steel Company's new plant at Gary. Among these are two 2,000-HP. motors, making 214 revolutions per minute, to drive the blooming-mills, and another of 2,000 HP., making 88 revolutions per minute, to drive the stand of rolls in which the finishing pass is given. One 6,000-HP. motor will drive the finishing-mills, second edger, and leader passes; another of 6,000 HP. will drive the high blooming-

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mills; and a third, also of 6,000 HP., will drive the dummy and first edger. These will make 88, 83·3, and 75 revolutions per minute respectively.

G. G. A.

Sinking with Air Hammer-Drills. E. K. JUDD.

(Engineering and Mining Journal, New York, 9 February, 1907, p. 289.)

The hammer-drill is rapidly coming into use throughout the United States. Its simplicity and light weight give it advantages over the more cumbersome ordinary air-drills which make it particularly suitable in narrow workings. The Author describes the sinking of a "slope" shaft in the Richmond coal-basin where these machines have been used with highly-satisfactory results, constituting, in his opinion, the most interesting feature of the work. The slope is 17½ feet wide at the bottom and 14½ feet at the top, the height being 7 feet. The dip is 33°. The rock is a coarse sandstone, which, though its constituents are very hard, is not strongly coherent, but breaks readily. In estimating the work done, account must be taken of the fact that only negro labour was used.

Ordinary air-drills were tried first, mounted on bars and tripods; but they were found cumbersome to handle, and the time spent in setting them up and moving them out of the way for a blast was too great in proportion to the time occupied in boring the holes. It was also difficult with these tools to keep the proper dimensions of the slope. The Jap hammer-drill, though easily handled, was too slow in boring and too complex in construction. The drill finally chosen was made by the Hardsocg Wonder Drill Company of Ottumwa, Iowa. It is extremely simple, having but one moving part, a partially hollow steel plunger $1\frac{7}{8}$ inch in diameter and 6 inches long, somewhat hardened and more solid at the striking-end. The hammer, which is easily handled by one man, strikes about 600 blows per minute. The bits used are made of 1-inch hexagon hollow-drilled steel. A set comprises 1-, 2-, 3-, and 4-foot bits, the cutting-end of the starter being $1\frac{7}{8}$ inch in diameter and that of the finisher 1¼ inch. The cutter is in the form of a six-pointed star. Before dressing the cutter, the smith drives a steel pin into the central hole to preserve its shape and size; and the swage for forming the edges and incisions of the cutting-face has a central projection for the same purpose. A graduated gauge is used to preserve the "follow" of the bits. The men work in shifts of six. Three men in the slope, assisted by a fourth, handle three drills. The other two dump the loaded trucks at surface. A round consisted of three horizontal rows of eight to ten 4-foot holes, the bottom row pitching steeply to break out a drag-cut. This row was fired first by electricity. It was a common feat to bore a 4-foot

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hole in 5 minutes, with 90 to 100 lbs. pressure. The average advance since the hammer-drills were adopted has been 60 to 65 and even 70 feet a month, not working on Sundays.

G. G. A.

Cost of Diamond-Drilling in Coal-Measures. W. F. Murray.

(Engineering and Mining Journal, New York, 23 February, 1907, p. 384.)

For exploring new ground for the purpose of ascertaining whether or not there is coal or ore in workable quantities there are several drills in common use; but by far the cheapest and the most satisfactory is the diamond core-drill when provided with the double-core barrel. This improved feature in diamond-drilling marks a great advance, for it enables unbroken cores, to show the character of the strata bored through, to be obtained. The cost depends on many conditions, the chief being the hardness of the rock; but the distance from which water, coal and supplies have to be brought may add greatly to the expense. Water is the most important item in diamond-drilling; without it the work cannot be carried on. Where water is scarce and the distance it has to be hauled considerable, it is a good plan to dig a pit and to line it with cement, so that the waste-water from the drill may be used again and again. The average cost of diamond-drilling in three separate districts in Colorado is shown in tabulated form. The strata bored consisted largely of a compact sandstone, with layers of clay and shale. In one district, where nine bore-holes reached a total depth of 4,736 feet, the average cost was 11*s.* 8*d.* per foot. In another district, where seven holes reached a total depth of 3,040 feet, the average cost amounted to 6*s.* 7¼*d.* per foot. And in the third district, where three holes attained a total depth of 1,767 feet, the average cost was 10*s.* 4½*d.* per foot.

G. G. A.

Modern Coaling-Station.

(Engineering and Mining Journal, New York, 17 November, 1906, p. 925.)

A coaling-station is in course of construction at Ashville, North Carolina, for the Southern Railway, possessing several novel features. The structure itself, which is 64 feet in length, 40 feet in width, and 85 feet 6 inches in height, is built throughout of concrete reinforced with corrugated-steel bars. It has on its western side a receiving-hopper 15 feet by 18 feet. The capacity of this large storage-bin is 1,000 tons of coal, 100 tons of wet sand and 15 tons of dry sand. A line of rails leads to the receiving-hopper, or bin, into which the coal is shot from the truck and from which it is taken up an elevator-

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shaft by buckets on an endless chain to the storage-bin. The elevator is driven by a powerful alternating-current electric motor, the loading-capacity being 100 tons per hour. A sand-elevator, driven from the driving-shaft of the coal-elevator, is capable of dealing with 10 tons an hour. Two lines of rail pass under the station, so that when an engine has to be coaled all that is necessary is to let down the shoot and to run the coal down into the tender. By means of 10-ton suspension-scales, fitted with *plus* and *minus* beams and an automatic registering-device, the coal may be weighed as taken on the engine.

G. G. A.

Ziegler Process for Coking Peat. Otto K. Zwingenberger.

(Engineering and Mining Journal, New York, 19 January, 1907, p. 143.)

The most modern, and by far the most scientific and rational method of utilizing peat, and the only really commercially successful one yet attempted, is that of converting it into coke with recovery of the by-products. As an industrial success this process was first established in Germany by Martin Ziegler. It was taken up by the Russian Government which erected works at Redkino. The most recent works, fitted with plant embodying the latest improvements, are at Beuerberg in South Germany. The Ziegler process consists in carbonizing air-dried peat containing about 25 per cent. of water in upright retorts. The raw material as it is dug from the bog is passed through a machine provided with screw-knives which break up its fibrous structure. In this machine it is kneaded and pressed forward to a mould which shapes the material into brick-forms of twice the size of a building-brick. These bricks are then exposed to the sun and air to be dried. The waste hot gases from the furnaces, mixed with air, can be advantageously used in a drying-chamber to complete the drying process. The dried bricks are fed into the top of the retort-ovens, the lower layers being drawn off from time to time into air-tight trucks which are run out on the line to cool. The by-products of distillation are saved as paraffin, phenolates, gas-oil, ammonia, acetic acid, ethyl alcohol and non-condensible gases. The last are used to heat the retorts, the only fuel required being coal or wood to heat the ovens for the first charge. When the gases become available the plant sustains itself.

The best peat gives 33 per cent. of coke, 4 to 5 per cent. of tar, 4 per cent. of tar-water and 22 per cent. of gases. The coke contains 87 per cent. of carbon, the ash seldom exceeding 3 per cent. The calorific value of this peat-coke is 14,500 B.Th.U. In appearance peat-coke is like charcoal, but it is as tough and strong as ordinary coke and has a metallic sound when struck. It is largely used for metallurgical purposes.

G. G. A.

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Relation between Fall of Barometric Pressure and Emission of Explosive Gases in Mines. G. BIGOURDAN.

(Comptes Rendus de l'Académie des Sciences, Paris, 1907, vol. cxliv. pp. 247-9.)

The fall of barometric pressure has long been observed to have an influence on the emanation of explosive gas in mines, and in this article the Author draws attention to the additional weight given to this observation by the conditions prevailing on the 28th January, 1907, when, almost at the same time, explosions took place at Lens and Saarbrücken. For three weeks before the 28th January the barometer was high, ranging during the 20th to 27th January between 763·0 millimetres (30·04 inches), and 770·7 millimetres (30·34 inches). At 10 A.M. on the 27th the reading was 768 millimetres (30·24 inches), and thereafter fell continuously until it reached 751·4 millimetres (29·58 inches) at 6 A.M. on the 29th. The explosions took place on the morning of the 28th, the pressure then being scarcely lower than the minimum for the preceding week. This confirms the remark made by J. Buddle that the increase in the emission of gases generally precedes by some little time the fall of the barometer. That which characterises the moment at which the explosions of the 28th January took place is the approach of an important barometric depression.

W. C. H.

Electrical Separation of Minerals.

(Zeitschrift für Elektrotechnik und Maschinenbau, Potsdam, 24 January, 1907, p. 3.)

This is a short article describing the principles of separating finely divided minerals by means of static electricity, depending on the fact that conductors take up an electric charge instantaneously when they come in contact with an electrified surface, whereas non-conductors require an appreciable time to do so. Instead of using an electrified surface the electric charge can be conveyed by induction. Diagrammatic representations of two separating-machines, one depending on contact and the other on induction, are given. The method has been applied on a considerable scale in America by Messrs. Blake and Morscher for the separation of zinc, copper and lead sulphides, and a comparison is given with the wet separation-process, much to the advantage of the electrical process. It is pointed out, that, in order to carry out the electrical process, the minerals must be very finely powdered and must also be completely dried, and this leads to the formation of a considerable amount of dust. The necessary drying leads to expense which in many cases would render the electrical method commercially inapplicable.

H. R. S.

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Location of Smelting-Works. H. Lang.

(Engineering and Mining Journal, New York, 23 March, 1907, p. 565.)

The Author discusses at some length and in considerable detail the relative advantages of the hillside or terrace as compared with what is known as the one-level site for smelting-works, and seeks to show that the common practice of choosing the former is an error in judgment due to neglect to take account of the changes in the means of transport which have taken place in recent years. Moreover, in his opinion, the advantages of the hillside, which affords opportunities for utilizing the force of gravity, have been greatly over-estimated, and they disappear entirely when the present system of railway-transport is adopted. To get the fall necessary to secure the full benefits of gravity, a hillside plant must be laid out downwards along the slope, or transversely to the contours. But railways must follow the direction of the contours, or nearly so; hence the lines must be transverse to the central line of the works. It follows from this that the railway lines cut the works transversely, instead of being parallel to the central line, or largest diameter of the plant. Consequently a greater length of line is required to bring all parts into communication, and there is thus not only a longer railway, but one consisting largely of gradients. One of the worst features of the hillside plants is that they cannot employ the best means of transport. The charging-bins are placed at the highest level, and as the materials have to be lifted, usually by railway-gradients, the favourable effects of gravity are to a large extent counter-balanced. Briefly stated, the main objection to the terrace site is the impossibility of adopting a simple and thorough-going system of transport which will answer all purposes throughout the works. The ore may be brought to the furnaces in hand-trucks or barrows; the slag from the furnaces may be carried to the dump in hand-pots, horse-drawn pots, or even in steam- or electrically-propelled vessels; but both operations cannot be carried on by the same means. But in the one-level system the ore may be brought to the bins; from the bins the charges may be taken to the furnaces, and from the furnaces the slag, matte or metal may be conveyed to the dump or store by a single means, the railway.

The tendency of modern designs shows clearly what the smelting works of the future will be. The plant will stand upon an extensive level space where there is ample room for all the buildings, railway lines, curves, switches and all else required in a large works. The rails will radiate from a common centre, which may be described as the focus of the works, and they will reach to all sources of traffic, the principal points being the furnaces, the sampling-mill, the weigh-scales, the slag- and ore-dumps, the storage- and feeding-bins and the store-houses. To make the best use of the facilities for transport, the structures will be placed with their longer side parallel with the lines, and not, as is now usually found, with their shorter side

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parallel thereto. The lines will be laid on one level to avoid gradients and the necessity of employing a locomotive whenever a truck has to be shifted a few feet. Curves, which cannot be wholly avoided, must be of the largest possible radius—never less than 200 feet. The gauge must be that of the connecting lines and should never be less than standard; much may be lost by laying narrow-gauge lines for the sake of initial economy. Finally, these lines, on which so much depends, should be laid out first, before anything else has been placed to interfere with the proper location. The use of the broad gauge tends greatly to simplify the design, construction and working of the smelting-plant, for not only are the different units, engines and trucks, of great individual capacity, power and durability, but they are correspondingly few in number. The simplification of the transporting-apparatus involves, or permits a corresponding improvement in several other features.

G. G. A.

Melting-Point of Blast-Furnace Slags. M. Simonis.

(Stahl und Eisen, Düsseldorf, 1907, p. 739.)

The Author has contrived an electric resistance-furnace based on the same principle as those of Cowles and Acheson—namely, the heat developed by the resistance of a body of granulated coal to the passage of an electric current of large volume. The heating-chamber is a cylinder of 135 millimetres diameter and 300 millimetres high, made of an extra aluminous fire-clay mass of which the melting point lies between Nos. 37 and 41 of the Seger scale. This is surrounded by a casing of coal containing about 3 per cent. of ash in grains 0·5 to 1·0 millimetre in diameter. The casing is 2 inches thick in the centre of the tube, but widens to 6 inches at the top and bottom, where it is connected with the electrodes, which are of sheet iron 3 millimetres thick. The thinnest part of the casing where the heat is highest is jacketed by a heat-insulating material kept in place by a series of binding-rings of fire-clay. With a current of 12 kilowatts at 100 to 120 volts the temperature can be brought up to 1,600° in 4 hours; but with a furnace of smaller dimensions, 65 millimetres in diameter, 8 to 9 kilowatts are sufficient to attain 1,600° to 1,700° in 1 hour. The conductivity of the furnace may be taken within tolerably wide limits according to the voltage, but it is necessary to have a margin in the watts available and not to make the heating mass too thin. An idea of the requirements for such a furnace may be obtained from the following figures. With 120 volts the current taken at first was 35 amperes, which increased to 90 amperes in 1 hour with a temperature of 1,100°, and to 125 amperes and 1,450° in 2 hours.

The samples of slag tested were pulverized and sifted between sieves of 900 to 5,000 mesh and moulded into trihedral pyramids of

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the usual Seger form with an organic binding material and dried. The tests were made by exposing them to the heat of the furnace on plates of graphite with the usual Seger tests and a Le Chatelier pyrometer. The results are given in the following table:—

No.	Works.	Class of Iron corresponding to Slag.	Melting Point.	
			Seger Scale.	° C.
			No.	
1	Dortmund Union . . .	Basic hot . . .	13	1,405
2	,, ,, . . .	,, normal . .	11	1,370
3	,, ,, . . .	,, cold . . .	10	1,350
4	Gutehoffnungshütte . .	Basic	10–11	1,360
5	Unknown	,, ...	12	1,390
6	F. Krupp	,, ...	11	1,375
7	Unknown	,, ...	9	1,335
8	,, ...	Foundry	12–13	1,400
9	Kraft	Hematite . . .	14–15	1,430
10	F. Krupp	,, low manganese . . .	10–11	1,360
11	,, ...	Hematite . . .	16	1,465
12	Gutehoffnungshütte . .	,, . . .	7–8	1,305
13	,, . . .	Ferro-manganese .	5–6	1,245
14	Georgs Marien Hütte . .	Silico-spiegel . .	10	1,345
15	Deutscher Kaiser . . .	Not given . . .	12–13	1,400
16	,, ,, ...	,, . . .	10	1,355

H. B.

Rate of Thermal Change of Elasticity. A. WASSMUTH.

(Wiener Berichte, vol. cxv, p. 223, and Beiblätter, Annalen der Physik, Leipzig, 1906, vol. xxx, p. 1171.)

According to Voigt the following relation exists between ΔT, the rise of temperature which occurs in a metal bar if its bending moment be changed from M_1 to M_2, and ϵ the rate of thermal change of the modulus of elasticity E.

$$\epsilon = \frac{E \cdot N \cdot \gamma \cdot \Delta T}{T (M_2^2 - M_1^2)}.$$

Here T is the absolute temperature, γ the thermal capacity (per unit of volume) and $N = \frac{d^6 \pi}{128}$ for round bars of the diameter d, or $N = \frac{d^6}{6}$ for square bars of the diameter d.

The Author determined the rises of temperature ΔT for several bars made of different metals, and from the results obtained he calculates ϵ.

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ϵ. Decrease of Modulus of Elasticity for 1° C. Rise of Temperature.

Platinum	0·0107 per cent.
Palladium	0·0205 ,,
Steel	0·0264 ,,
Nickel	0·03247 ,,
Copper	0·0359 ,,
Gold	0·0409 ,,
Silver	0·0748 ,,
Aluminium	0·1998 ,,
Zinc	0·0349 ,,

In the case of alloys ϵ is the mean of the several constituents. In fact, the value for zinc was obtained indirectly by experimenting on brasses having different proportions of zinc and copper.

C. E. S.

Efficiency of Furnaces. Dr. Joseph W. Richards.

(Journal of the Franklin Institute, Philadelphia, February, 1907, pp. 129–140.)

The subject is considered under two aspects:—(1) as regards the thermal efficiency; and (2) in the more general aspect of efficiency, which is obtaining at a minimum cost the result for which the furnace is designed. Under thermal efficiency the Author distinguishes two classes of operations, (1) those requiring a definite amount of thermal effect to be produced independent of time; and (2) those requiring the application of temperature for a given time. He further subdivides class 1 into three groups:—(*a*) when the desired change is merely one of temperature; (*b*) when the change is a mixed chemical and physical effect; (*c*) when the change is merely a chemical transposition. Numerical illustrations of all these groups are given and the calculations are of a simple nature. The following are some of the numerical examples worked out for group (*a*):—Iron-foundry cupola (thermal efficiency 26·0 per cent.); steel crucible (3·37 per cent.); electrical furnace (55 per cent., not including thermal efficiency of generating the electric energy); regenerative gas-furnace (27·3 per cent.). Under group (*b*): crucible in which magnetite is added to pig-iron, causing absorption and evolution of heat due to chemical changes (3·0 per cent.); open-hearth furnace, into which, after the temperature has been raised to 1,250° C., red hematite ore is added to oxidized impurities (17·7 per cent.). In group (*c*) only a chemical transposition is produced, and the heat in the final product is not a desideratum, and theoretically can be utilized by being returned to the furnace. The heat absorbed by the chemical reactions is then the net thermal work accomplished by the furnace. A blast-furnace is taken as a numerical example and the thermal efficiency works out to 26·9 per cent.

Efficiency of the furnace in its general aspect is considered under the several usual heads, such as cost of fuel, repairs, labour, etc.

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The somewhat neglected item of expenditure, the interest on the value of the material treated, is discussed at some length, and it is shown that in certain cases this may be the determining factor in deciding the type of furnace to be adopted. A comparison is made, for instance, between a 50-ton open-hearth furnace and a Talbot continuous furnace. The condition however applies principally to the smelting of copper, silver and gold.

H. R. S.

Welding Steel by Alumino-Thermit.

(Le Génie Civil, Paris, vol. 1, pp. 158–60.)

Thermit is a mechanical mixture of oxide of iron and granulated aluminium, two substances capable of re-acting on each other with the production of pure iron, at a temperature of about 3,000° C., and alumina. On allowing the molten iron at this high temperature to come in contact with two pieces of iron or steel to be welded together, the latter are quickly brought to the point of fusion and the joint thus made becomes, on cooling, remarkably sound. Experiments have recently been made in joining together, by this means, steel bars 130 millimetres (5·12 inches) square. To effect this the ends to be joined were placed in juxtaposition, with a space of 20 millimetres (0·8 inch) between them; the whole being enclosed in a mould of sand, of such form that the section at the joint after the molten iron was run in would be 60 millimetres (2·4 inches) larger each way than the normal section of the bar. When all was prepared and the mould closed, the hot gases from a portable fire were drawn through, and as soon as the bars had acquired a cherry-red heat the molten iron produced by the thermit was run in. When cold, the joints made in this manner were subjected to both tensile- and bending-tests, and were found to be fully equal to the rest of the respective bars. Some important repairs have been effected by the use of thermit, notably, one to the port propeller-bracket of the S.S. *Friedrich der Grosse*. This bracket had been necked off near its junction with the hull. The break was dressed back sufficiently for the two sides to be 30 millimetres (1·2 inch) apart when the propeller-bush was in its true position; the whole was then enclosed in a sand-mould and heated, after which the molten iron from the thermit was run in. The repair, which proved quite successful, was completed in four days, 350 kilograms (770 lbs.) of thermit being used. Another case of the use of thermit was that of the S.S. *Apache*, of which the stern-frame was repaired. Subsequently, owing to the propeller fouling a floating body, the frame was again bent, but the joint remained without sign of fracture.

I. C. B.

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Preparation of Iron Sections for the Microscope.

Prof. E. Heyn.

(Mitteilungen aus dem Königlichen Materialprüfungsamt, Gross-Lichterfelde West, 1906, vol. xxiv. p. 253.)

This article is illustrated by large photographic reproductions of steel sections. The Author's experiments are directed chiefly to show that copper chloride of ammonia solution is superior to hydrochloric acid. The first of these chemicals has to be dissolved in 12 parts of water; with less water the attack is too severe; with greater dilution the copper which is deposited adheres to the steel. After etching, those regions which are rich in phosphorus appear of a darker hue than others, due, it is believed, to a combination of the copper and phosphorus. No discoloration is noticeable with hydrochloric acid, but it seems to attack most vigorously those parts which are rich in phosphorus. In steels containing specks of phosphides of iron, hydrochloric acid eats deep pits which have generally been mistaken for pores or patches of cinder.

An experiment was carried out for ascertaining the relative rate at which dilute hydrochloric acid attacked two steels respectively poor and rich in phosphorus. Their analyses were as follows:—

Samples.	S. 660·0.	S. 664·6.
Carbon	0·07	0·08
Manganese	0·10	0·27
Phosphorus	0·01	0·28

After exposing the samples to the action of the acid for 3½ hours and re-weighing, it was found that sample S 664·6 had lost eighty times as much per unit of surface as S 660.

Although copper chloride of ammonia attacks the phosphides which are dissolved in the ferrite and colours these parts brown, it will not attack those parts in which the phosphorus exceeds 1 per cent. These regions or specks therefore appear bright under the microscope. Whether these portions are acted on by hydrochloric acid is not stated. The copper chloride of ammonia also darkens those regions of steel sections which have been subjected to severe strains. This darkening is said to show stress lines. The stresses must evidently disappear after the sections have been prepared, but no experiments were made to see whether old sections behaved differently from newly prepared ones. Great stress is laid on the necessity for agitating etching fluids, for otherwise the edges and other localities of the sections are irregularly attacked. The article also deals with the results of nicking and bending tests of some of the samples which were examined microscopically.

C. E. S.

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Utilization of Swedish Nickel-Ores. H. Hullegård.

(Teknisk Tidskrift, Stockholm, 1906, Chem. and Mining section, pp. 127–8.)

The manufacture of nickel was a flourishing industry in Sweden till about twenty years ago, when it became depressed through foreign competition, in which the foremost place was won by the Orford Copper Company of Bayonne, New Jersey. There a crude Canadian ore, containing 30 to 40 per cent. of copper and an equal quantity of nickel, is smelted in an upright furnace with charcoal and sulphate of soda. The sodium sulphide thereby formed dissolves a large part of the copper sulphide, while the greatest part of the nickel sulphide remains insoluble; so that, when the molten mass cools, it settles in two distinct layers, the upper containing chiefly copper and the lower chiefly nickel. By three repetitions of this treatment a nickel sulphide is produced containing about 1 per cent. copper, which, after being pulverized in a ball-mill, is steeped first in water to dissolve smaller quantities of sodium sulphide, and then in dilute sulphuric acid, which dissolves the small quantity of iron sulphide present. By further processes the separation is effected of any copper, cobalt, silver, platinum and palladium; and all of these precious metals are saved, leaving protoxide of nickel for sale, or for smelting with charcoal to produce metallic nickel.

Swedish nickel-ores contain in general too little nickel and too much iron to be worked on the Orford plan. But as the larger part of the metallic nickel manufactured is employed for making nickel-steel, the Author asks why the great trouble should be incurred of freeing nickel from the iron associated with it, in order that it may again be mixed with iron to form nickel-steel. He therefore urges that direct production of nickel steel is the only way in which poor Swedish nickel-ores can advantageously be utilized. He has recently met with magnetic pyrites, containing 1 to 3 per cent. of nickel, which is free from arsenic and phosphorus, and admits of very simple treatment: the sulphurous gases driven off in roasting it are utilized for making sulphuric acid or sulphite. The roasted regulus, being briquetted and smelted with charcoal, forms nickel-iron containing somewhat more than 3 per cent. nickel, in which state there is the largest field for its use.

A. B.

Influence of Temperature on the Brittleness of Steel. G. Charpy.

(Mémoires de la Société des Ingénieurs Civil de France, Paris, Bulletin d'Octobre 1906, pp. 562–9.)

This Paper describes the results of a series of tests made to determine the influence of temperature on the brittleness of steel. The steel tested was of five different kinds:—(1) a very soft steel made

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by the Thomas process; (2) a very pure mild steel by the Martin process; (3) a medium steel by the Martin process, which was compressed during solidification; (4) a harder steel by the Martin process, containing a little nickel; (5) a steel by the Martin process containing both chrome and nickel. The chemical composition of the various steels is given in the text.

The Author describes the preparation and method of testing the different specimens, special care having been taken to ensure, as far as possible, the absolute uniformity of the specimens and their treatment and the temperature at which they were tested. The first series of tests was carried out at the normal temperature of the atmosphere. The tests were made by means of an impact testing-machine. The bars were all nicked in precisely the same manner and the resilience was measured by the work done upon the bar by the testing-machine divided by the net section of the bar. The temperature tests were then made on precisely the same lines at temperatures of $-80°$, $-18°$, $+30°$, $+97°$, $+200°$, $+290°$, $+350°$, $+425°$, $+500°$ and $+600°$ Centigrade. At each temperature two bars of each of the various metals were tested. A table is given showing the results of the tests, and the results are also shown graphically on two diagrams in the text. In every case, and for all the steels tested, it was found that the resilience, which varied inversely as the brittleness, increased with the rise of temperature (commencing at low temperatures), reached a maximum between $+100°$ and $+200°$, diminished afterwards to a minimum between $400°$ and $500°$ (blue heat), and increased again as the temperature rose towards a red heat. The variations were especially important for the soft metals. In the case of the softest steel (No. 1), a fall of temperature from $+20°$ to $-20°$ was sufficient to decrease the resilience in a ratio of 6 to 1. Steel No. 2, which was of much purer quality, also showed great variations, and it was remarkable that this steel, which after suitable thermal treatment could be bent double at ordinary temperature, broke like glass with a scarcely measurable resilience at the temperature of $-80°$, and was much more brittle under these circumstances than steels Nos. 4 and 5, which appeared to show a great superiority as regards the effects of temperature on their brittleness.

The practical conclusions drawn from the tests were:—(1) that by the employment of special steels (chrome and nickel) the troubles resulting from variations of temperature can be almost completely avoided, including the brittleness caused by blue heat; (2) that the increase of brittleness in the softer steels when subjected to low temperatures requires serious consideration, especially when these steels are of doubtful purity.

J. M. M.

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Asphaltic Limestones of the Gard, France. P. Nicou.

(Annales des Mines, Paris, 1906, 10 Ser., vol. x, p. 513.)

In the lacustrine tertiary basin of the Department du Gard the existence of limestones containing bitumen has been known for a considerable time, the pitchy substance oozing from the rocks at the surface having found a certain use as cattle medicine among the local farmers, but it was not until 1844 that any mining concessions were granted. Since that time mining has been carried on in an intermittent fashion with a comparatively small production, but recent discoveries in the neighbourhood of the existing mines seem to indicate the presence of deposits of considerable importance in depth.

The bituminous indications in the district, which is situated on the level ground between the eastern slope of the Cevennes and the Rhone, are contained in a narrow belt of ground 1½ mile wide extending from a point about midway between Alais and Avignon for 22 miles in a north-easterly direction, the principal workings being concentrated about Mons and Servas at the southern, and Saint Jean de Maruéjols at the northern end. The geological age is Lower Oligocene, the group of strata immediately above the London Clay. The formation consists of alternations of limestones, marls and sandstones about 650 feet thick, the valuable bituminous constituents being restricted to the limestones, where they are irregularly distributed in patches, the best quality containing 12 to 13, the second 10 to 11, the third 8 to 9, and the poorest quality 4 to 6 per cent. of bitumen in the beds actually workable. At Mons three beds, 7½, 2½ and 6½ feet thick respectively, dipping 1 in 4 to 1 in 3, have been worked to a depth of 250 feet below the surface with a collective thickness of workable mineral, with 10 per cent. of bitumen, ranging between 5 and 13 feet in the two larger beds, the thinner middle one being too poor to work. Between 1844 and 1905 about 80,000 tons have been extracted, the maximum of 4,600 tons having been attained in 1890, but since that date the production has fallen off on account of stoppages due to influx of water. The richer rock was mostly sent to England, the lower quality being utilized for mastic at Alais.

At Saint Jean de Maruéjols the total thickness of the bituminous formation is 35 to 40 feet, giving an average of 8 feet of workable first and second class quality. The bed dips 20° and has been worked on the incline for 650 feet, about 25 per cent. of the rock being left as pillars. In 1904, however, a considerable fall of ground took place in the old workings, and in consequence a more systematic method of working with larger pillars, and partially filling with waste rock, has been adopted, leaving only 25 per cent. of the ground open, but allowing of the removal of only half the mineral. About 130,000 tons have been produced, of which 60,000 were of first (12–14 per cent.) quality, 55,000 of second (8–9 per cent.) for export, the remainder being converted into mastic on the spot. Between 1880 and 1890 the mineral was mostly sent to India,

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but now its destination is either London or Berlin. The average cost of transport to the former place is 18*s.* 6*d.* per ton, made up of cartage to railway, 8 miles, 2*s.* 4*d.*, railway carriage to Marseilles 5*s.* 4*d.*, shipping dues 1*s.* 6*d.*, and sea-freight 10*s.* The output of the mine between 1902 and 1905 was 5,000 to 8,000 tons per annum.

During the past few years several borings have been put down by the Société Francaise des Asphaltes, the Val de Travers Company and others, which seem to prove the continuation of the deposit of Saint Jean in depth to about 600 feet below the outcrop, but with a considerable increase in thickness, the workable thickness varying between 16 and 36 feet. The asphalt from the mines of the Gard is suitable both for compressed paving and mastic, and as such is allowed by the City of Paris for paving purposes, the rock being pulverized to pass a screen of 1-inch mesh with a final content of 6 to 13 per cent. bitumen; no rock to be used with less than 5 per cent. The prices for rock asphalt in London in October, 1905, were per ton of 2,240 lbs.:—

	£	*s.*	*d.*
Val de Travers	2	0	0
Ragusa, Sicily	1	7	6
Pyrmont, Seyssel	2	0	0
Mons, Gard	1	15	0

for material containing at least 8 per cent. of bitumen and suitable for compressed paving.

H. B.

Cubic Compressibility of Rocks. F. Adams and E. Coker.

(Silliman's Journal, 1906, vol. xxii, p. 95, and Beiblätter, Annalen der Physik, Leipzig, 1907, vol. xxxi, p. 186.)

The Authors refer to the work of Nagaoka,[1] who bent and torded various rocks, and point out that his methods were not reliable, more particularly as the samples dealt with did not appear to be truly elastic. The Authors, therefore, took great pains in the choice of their materials, and had them shaped into test-pieces, either 1 inch square or cylindrical and 3 inches long. The cubic compressibility was in this case also not measured by the direct method, but measurements were taken of the longitudinal contraction and lateral expansion under a longitudinal stress from which data all the elastic properties could be estimated. Sixteen rocks were dealt with, of which the more important results are as follows:—

Modulus of Cubic Compressibles.

Marbles and limestones	4,050	tons per square inch.
Granites	2,800	,, ,,
Basic rocks	5,280	,, ,,
Glass	4,170	,, ,,
Steel	16,600 to 17,500	,, ,,

C. E. S.

[1] See Beiblätter, Annalen der Physik, vol. xxiv, p. 1246.

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Towing with Steel Ropes and Chains. G. Lovisetto.

(Rivista Marittima, Rome, November, 1906, pp. 211-53.)

A description is given of the towing of the *Vittorio Emanuele* by the *Silicia*—both ships of the Italian Navy—from Naples to Spezia and back. On account of the large tonnage of the vessels, the displacement of the *Silicia* being 13,000 tons, and that of the *Vittorio Emanuele* 7,600 tons, great attention was paid to the dimensions and composition of the cables employed. The Author discusses at some length the various properties of different kinds of cable, and gives numerous diagrams and curves showing the values of the horizontal tension and sag for varying velocities and distances apart of the two vessels. From these investigations the approximate rule is deduced that the most suitable size of cable to adopt is one of which the weight per metre-length is one hundredth part of the amount of the horizontal tension in the cable when towing a vessel at the most convenient velocity in a rough sea. The various cables considered were of a total length of approximately 250 metres (820 feet) as this distance allows of a maximum oscillation of 100 metres (328 feet) without bringing the vessels nearer together than 150 metres (492 feet). The maximum oscillation of 100 metres is taken as being the mean average length of a wave in stormy weather. For the towing of the *Vittorio Emanuele* it was decided to use two cables, each composed as follows:—fifty metres of chain of 50 millimetres (2 inches) thickness at the centre; one hundred metres of steel rope 19 to 20 centimetres (7½ inches) in circumference at each end. At a velocity of 10 miles an hour in a calm sea the tension in each cable was about 7,000 kilograms (7 tons). At certain points of the journey, where it was found necessary to reduce the velocity to about 4 miles per hour, no inconvenience was experienced from the dragging of the cables on the bottom.

Tables showing weights and breaking strengths of various cables are given, also diagrams and photographs showing the method of attaching the cables at both ends.

L. F. M.

Latent Heat of Evaporation of Water between 30° *C.* (86° *F.*) *and* 100° *C.* (212° *F.*). F. Henning.

(Annalen der Physik, Leipzig, 1906, vol. xxi, p. 849.)

This article, which extends over thirty pages, recapitulates the results of other experiments, and after describing those made by the Author gives his results as follows:—

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Temperatures.		Latent Heat of Evaporation.	
° C.	° F.	Calories.	B.Th.U.
30	86	579·6	1,043·3
40	104	574·2	1,033·6
50	122	568·6	1,023·5
60	140	562·9	1,012·2
70	158	557·0	1,002·6
80	176	551·1	992·0
90	194	545·0	981·0
100	212	538·7	969·7

C. E. S.

Stationary Water-Purification Plant. Dr. Haefcke.

(Gesundheits-Ingenieur, Munich, 27 October, 1906, pp. 667-9.)

The various methods of procuring an absolutely pure water-supply for isolated buildings, such as hospitals and barracks, are discussed by the Author, and it is pointed out that neither by means of filtration, nor by treatment with chemicals, is it possible in all cases to obtain water equally free from impurities to that heated to a temperature of 100° C. In some cases, however, the boiling process tends to render dissolved substances no longer soluble and thus to make the water turbid or discoloured. An account is given, with illustrations, of the Henneberg apparatus for the preparation of drinking-water, which ensures that all the water passing through it must reach a temperature of 105° to 110° C. The water under treatment travels slowly through a worm situated in the hottest zone of the boiler and cannot fail to reach the required temperature to ensure perfect sterilization. An essential part of the apparatus is the cooling arrangement, whereby the outflowing heated water is made to transfer its heat to the incoming supply, and by means of this heat-exchange the sterilized water can be reduced to a temperature only 3° to 5° above that of the feed-water. There is also a filter attached to the plant, which is employed to remove from the purified effluent any admixture of earthy or vegetable matters, and provision is made for injecting an air-current, which tends to extract from the cooled sterilized water any remnants of the slightly nauseous taste due to the boiling process. Special precautions are needed in the treatment of water rich in iron. It is essential to take the readings of the manometer attached to the boiler to see that the requisite degree of superheat is attained, and an electric signalling-thermometer is inserted into the outlet, which at once gives a warning when the minimum temperature falls below a fixed standard. The apparatus is made in various sizes to deliver 110 to 2,200 gallons hourly.

G. R. R.

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Water-Supply of Berlin. ANKLAM.

(Gesundheits-Ingenieur, Munich, 26 January, 1907, pp. 53-9.)

After a brief historical sketch of the subject of the Berlin water-supply and the formation of an English company, which obtained a monopoly for this purpose for 25 years from July, 1856, expiring in 1881, it is stated that the works, yielding a supply for 300,000 inhabitants carried out by that company, were first started in April 1856. The progress of this undertaking, which in 1873 was earning a dividend of 12½ per cent., is set forth, and the further works undertaken by Mr. Henry Gill, after the company's interests had been acquired by the Berlin authorities in July, 1873, for about a million sterling, are described. The position of the new waterworks on Lake Tegel is shown by a plan, and the sum of £650,000 was voted for their construction in August, 1874. These works were completed in September, 1877, when the total available supply of water was 13,200,000 gallons per day from the original Stralau works and 9,900,000 gallons daily from the new works on Lake Tegel. This latter supply was drawn from 23 double-lined wells sunk to a depth of 65 feet below the water-line. The water, at first clear, became turbid after seven months' working, and both the mains and reservoirs were filled with the growth of *crenothrix*, due to the presence of iron. The experiments undertaken by the Author to remove the iron by aeration are discussed, but ultimately the authorities decided to abandon the wells and to substitute a supply of filtered water from the lake. In November, 1883, after seven years' use of the well-water, the first supply of filtered water from Lake Tegel was distributed. The extension of the town rendered an enlarged supply of water necessary, and owing to the increasing pollution of the River Spree it became evident that the first works would eventually have to be abandoned. As early, therefore, as 1887, Mr. Gill prepared plans for further works on Lake Müggel, which, together with those on Lake Tegel, would be sufficient to furnish water for a population of 2½ million persons. The Stralau works were given up in 1893, and extensions of the new works made it possible in that year to distribute a daily volume of about 53 million gallons. The cholera scare in Hamburg in the same year rendered it advisable to attempt to procure well-water in place of that drawn from the lakes, and the possibility of supplying Berlin from numerous tube-wells was investigated. Seeing that a supply of 22 gallons per head daily for a population of 2½ millions would render it necessary to provide not less than 55 million gallons of water per day, rising ultimately to 99 millions of gallons, or even more, it was a question whether such a volume could be obtained by pumping in the vicinity of Berlin. It was reported by the Geological Institute that the valley of the Spree is a portion of the ancient bed of the Oder, which stretches as far as Warsaw and there unites with the former valley of the Vistula. This old river-bed is fed by water from the mountains, which is abundant in quantity

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flowing underground towards the sea. By means of tube-wells driven to the level of the subsoil-water a supply of great magnitude can be obtained. Subterranean galleries were therefore driven in various directions and numerous tube-wells were sunk. The gradual extension of the supply by this means is traced, and the method of freeing the subsoil-water from iron is explained. In the "A" gallery of the works on Lake Müggel, which has a total length of 8,988 feet, there are 103 collecting-wells; in gallery "B," 15,091 feet in length, 169 wells; and in gallery "C," 7,218 feet in length, 78 tube-wells. Of this total 303 wells are now in operation. The amount of iron in solution averages 1·2 milligram per litre. The works for purifying the water are illustrated and statistics are given of the volume of water supplied by the two great works on Lakes Müggel and Tegel.

G. R. R.

Water-Supply to Christiania from the River Aker.[1] L. Egeb.

(Teknisk Ugeblad, Christiania, 1907, pp. 21–2.)

In a Paper read to the Society of Norwegian Engineers and Architects, the Author gives the annual rainfall as averaging 38·43 inches over the Aker watershed of 86 square miles, with a variation of 25½ per cent. above and 29½ per cent. below this amount. The works along the course of the river are estimated to require 1,100 gallons per second, which in dry years is more than can be maintained without curtailing the hours of supply. Measures are now being taken for enabling this quantity to be maintained during dry periods, for which purpose a storage capacity is required of 30,000 million gallons, or 11,200 million gallons more than the existing storage. The cost of enlarging the several reservoirs in the watershed will range between £20 and £66 per million gallons capacity. In the construction of the reservoir-dams the several courses of masonry, instead of being laid on a level bed, are tilted in order to guard against slipping; and the longer dams are convex on the water side, with a radius of 500 to 650 feet with a view to prevent cracking under changes of temperature. When the whole height of fall is utilized it will amount to 460 feet, which, with 1,100 gallons per second, and turbines of 75-per-cent. efficiency, represents an aggregate of 7,000 effective HP. There is now a practically constant flow issuing from Maridal lake into the Aker river; but there are many causes of variation in the supply before it reaches the works lowest down the stream. Along the course of the river these conditions have now been highly ameliorated by recourse to self-acting apparatus for immediately letting the water go by if a turbine stops; if the water-level rises or falls

[1] Minutes of Proceedings Inst. C.E., 1900, vol. cxli, p. 395; and 1901, vol. cxlvii, p. 477.

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beyond the limits allowed for the proper supply, a float opens or closes a by-pass. The average consumption per head per day in large towns is said to range as follows:—

North America	300–500 litres,	say	66–110	gallons.
England	136–230 ,,	,,	30–50	,,
France	210–450 ,,	,,	46–100	,,
Germany	260 ,,	,,	57	,,

The rate of increase was estimated at 12 per cent. every five years by Mr. Beer, engineer of the Berlin waterworks, when he was consulted in 1899 about an increased supply for Stockholm. For Christiania the work at present in progress comprises the construction of roads, erection of buildings and driving of tunnels. The area of the tunnels is 38 square feet, their height 7·71 feet, and their width 5·9 feet, with circular arch and invert. They are ventilated by fans driven by electric motors at the tunnel-entrances. The gradient is 1 in 1,000, which should give a maximum velocity of 2·6 feet per second, with a flow of 590 gallons per second. In order to avoid faults a number of alternative routes had to be surveyed before the lines of the tunnels could be decided on. For five tunnels, having an aggregate length of 4,185 yards, the total cost averaged 82*s.* per yard. The miners' pay has averaged about 5*s.* 7*d.* per shift.

A. B.

Recent Practice in Hydraulic-fill Dam Construction.

J. D. Schuyler, M. Am. Soc. C.E.

(Proceedings of the American Society of Civil Engineers, New York, October, 1900, pp. 780–837.)

The Paper treats of the methods used in Western America in constructing dams for water-storage by the agency of water for loosening, conveying, assorting, distributing, depositing and consolidating the materials. It is stated that when the height of an earthen dam exceeds 100 feet, it is believed that a cheaper and more efficient method of construction of earthen dams than the older method has been found in the perfected system of hydraulic-fill construction, which had its origin in the hydraulic mining regions of California. The entire work is done by the agency of water, which is brought in large volume to the site of the dam in ditches and pipes, and delivered through the nozzle of a flexible and easily-controlled device, called a hydraulic monitor, with which hydraulic mining is performed. The stream issues from the nozzle of the monitor with a velocity of 100 to 200 feet per second, and is directed against the face of the hill containing the materials desired for use, and by undermining cuts it loosens everything in its path except solid rock. The disintegrated mass is washed with the water down the steep sluice-way provided, and conveyed through flumes and pipes to the several points on the dam selected for the deposit of the different

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grades of material. The Paper gives accounts of the construction of dams built on this principle, and of that of dams in which a portion consists of rock-filling. A tongue of puddle or concrete is first carried down into the impervious strata below the dam-site. The theory on which hydraulic-fill dams are generally planned and attempted to be carried out is:—that the middle third of the dam should be composed of materials which by draining and natural settlement will consolidate into a mass impervious to water and remain in a moist, semi-plastic condition; and that the outer halves of the other thirds of the width should consist of coarse, porous, open materials, through which the water draining from the interior would pass freely; whilst the inner halves of the outer zones should consist of a mixture of the coarse and fine, or semi-porous material in a condition to act as a filter, so as to prevent the escape of the fine particles from the middle third, but at the same time to allow of the slow percolation of water through it. The essential condition in an earth dam is to secure a sufficient mixture of materials, having particles so fine and so closely placed in juxtaposition as to oppose friction to the water seeking to penetrate under pressure between these particles to an insuperable degree, or so that if water in moderate amounts does find its way through it shall be robbed of all velocity and power to transport any of the particles of the embankment with it.

With respect to dams consisting partly of rock-filling, it is stated that the ideal type of earth dam is one where stability of the mass is secured by a heavy embankment of loose rock on the down-stream side, against which the earth-filling can be placed by the sluicing method, so as to have an up-stream slope of at least 4 to 1. In some cases the rock-filling was placed with slopes of $1\frac{1}{2}$ to 1 on the down-stream side and $\frac{3}{4}$ to 1 on the up-stream side, being 10 feet wide at the crest.

A. W. B.

Tests of Reinforced-Concrete Reservoir-Vaulting.

(Revista de Obras Publicas, Madrid, vol. lv, p. 39. 16 Figs.)

A new storage-reservoir to contain 4,414,500 gallons of water is in process of construction for the town of Gijon in Spain. The formation of the reservoir itself is being carried out under the supervision of Mr. Bellido, the municipal architect of the town, and the contract for the vaulting over the reservoir has been let to Mr. Ribera. The vaulting itself is being built of reinforced concrete, and the present article describes the dimensions of the structure and the tests to which certain portions of the vaulting were subjected in the presence of a large number of engineers. Three vaults were built in one of the angles of the reservoir, and were supported by four girders, each of which rested on two columns, placed 13·12 feet apart centre to centre, so that the actual area covered by each vault was 172 square feet. Each column was 7·8 inches square in cross-

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section, was reinforced with four bars 0·6 inch in diameter, and rested on a base 15·6 inches square. Each girder was reinforced with two bars 0·5 inch in diameter, and two bars 1·3 inch in diameter, the latter in compression; the cross-section of the girder was 31·5 inches by 7·8 inches. The clear span of each vault was thus 12·46 feet and its thickness 2·36 inches at the crown and 4·72 inches at the springing. The reinforcement consisted of three bars 0·4 inch in diameter per metre, and other bars were interlaced with these. The rise of the vault was 15 inches. Illustrations show the arrangements and also the methods of loading for the tests. The concrete used consisted of 5 bushels of gravel and 1 bushel of sand to 100 lbs. of Portland cement. Various distributed loads were put on the vaults, the maximum being 438 lbs. per square foot of area covered by the vaults, and with this load the structure collapsed. The vaulting was designed for a load of 80 lbs. per square foot, so that the construction was very satisfactory.

E. R. D.

Reinforced-Concrete Reservoir at Waltham, Mass.

BERTRAM BREWER.

(Engineering Record, New York, 12 January, 1907, pp. 32-3.)

The water-supply being pumped from a well, this circular structure was built for storage. It is 100 feet in diameter and 43 feet high. The floor is 12 inches thick, reinforced with a layer of expanded metal near the surface, and connected with walls by bent rods 12 inches apart penetrating 6 feet into the floor and 3 feet into the wall. The latter is 18 inches thick at bottom and 12 inches at top battering outside; and the reinforcement is of $1\frac{1}{8}$-inch round rods with laps of four diameters, the number being such that the tensile stress is within the 12,000-lb. limit. The roof is of reinforced-concrete slab 3 inches thick, supported by steel trusses radiating from a central concrete-covered pipe-column, which serves also as an overflow. Except in the foundations and lower 6 inches of floor, where it is of 1:3:6, the concrete is of 100 lbs. cement to 2 cubic feet of sand, 4 cubic feet stone and 5 lbs. hydrated lime. The introduction of the latter constituent and the use of gravel up to $1\frac{1}{2}$-inch diameter, including round pebbles, so as to pack easier, with the view of greater impermeability, form the speciality of the work. The water-proofing was also helped by the treatment of the joints between layers, and the coating inside of a special mixture of sand, cement, lime and Medusa compound. All this was the result of careful experimenting with these and other proportions and compounds.

Except for a certain amount of seepage, which is so small as to be of no lasting harm to the structure, the desired result has been attained.

C. O. B.

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Electrical Indicator for Water-Tanks. C. H. Glasser.

(Engineering and Mining Journal, New York, 2 February, 1907, p. 227.)

The Author describes and illustrates the construction of an electrical water-level indicator for service-tanks and pumping-stations. The depth of the tanks in this case was 19 feet, and an apparatus was asked to indicate the height of the water by direct readings to the nearest even foot at any desired number of stations. The difficulty was to obtain an apparatus of sufficient simplicity to warrant its adoption for practical use. Several devices were rejected, as being too complicated. The one finally adopted is simple, gives accurate readings at any desired point, or number of points, and requires only two wires. A lever-float, in length nearly equal to the diameter of the tank, which is 30 feet, is hinged to the inside of the tank near the top. Close to the fulcrum-end of this lever an arm is attached at right angles, carrying a segmental copper strip. As the float rises and falls this strip makes and breaks contact with nineteen fixed copper contact-buttons, each representing a foot of water in the tank. These buttons are on a stationary board, and the moving copper strip, to which one of the main wires is attached, rubs over them as the float rises and falls. The contact-buttons are connected in parallel through a lamp-resistance to the other wire of a 220-volt circuit. The two wires of this circuit are run to the points where indications are required. At these points ammeters are inserted, which show by the current-strength the number of lamps in circuit, and thereby indicate the water-level. The ammeters are calibrated to give a full deflection with a current of 5 amperes, and scale-markings are one to twenty, consuming 0·25 ampere to each division. At the power-house a recording ammeter is used, which gives a chart-record of the depth of water at all times.

G. G. A.

Sinking and Lining a 6-Foot Well 80 Feet Deep in Water-bearing Soils.

(Engineering Record, New York, 16 February, 1907, p. 178.)

The recent sinking of a shot-tower well at East Alton, Illinois, involved great difficulties. The strata, being fully charged with water, necessitated special construction-operations and permanent waterproof lining. The preliminary casing was made in eight vertical cylindrical sections built of $\frac{5}{16}$-inch boiler-plate. Each of these had a $1\frac{1}{2}$-inch by 3-inch reinforcing-ring at top and bottom, the top ring being riveted to the outside and the bottom to the inside. The section at top was 10 feet 6 inches in diameter, the

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next one 10 feet 1 inch, and so on, so that the sections could be telescoped and caulked. Each section was prevented from sliding over the one below it by ½-inch by 3-inch angles bolted to it, these angles also locking the sections together.

The difficulties in attaining sufficient pumping-power, and in forcing the casing down, were remarkable, and are detailed in full. When eventually the bottom was reached, it was sealed with sacks of concrete, the water then being permitted to rise temporarily to relieve the pressure in setting. The concrete floor was then put in. The lining was made in six concrete segments 10 feet long, and the joints were caulked with fresh oakum, and dried white-pine tongue- and grooved-wedges were driven into them, these being covered with strips of tin. The concrete mixture was 1 : 2 : 4, the cement containing 1½ per cent. of Medusa waterproofing compound, after testing other waterproofing substances, such as alum and soft soap, and hydrated lime. After some months of dampness the concrete became as dry as that above ground.

C. O. B.

Hydraulic Well-boring Apparatus.

(Zeitschrift für Elektrotechnik und Maschinenbau, Potsdam, 9 January, 1907, p. 18.)

In this apparatus the boring-head is of the impact type; but the lifting- and releasing-mechanism, instead of being at the surface, is close up against the boring-head, and is worked by hydraulic pressure. It consists of an external tube sliding in the bore-hole, to which the cutter is fixed, and of an hydraulically-actuated device secured to the boring-rod, the latter being in the form of a pipe, which supplies the pressure-water. Directly the external tube forming the tup falls, a lever, which had previously been resting on a ring fixed to the inside of the pipe, is released, and a valve is opened, and thus the hydraulic device, which is telescopic, is extended by the hydraulic pressure until it overtakes the tup and catches hold of it by means of two hooks. At the same time the lever is engaged by the ring previously mentioned, so that the valve is closed, and the pressure-water then acts so as to lift the tup. At the top of the stroke the two hooks are tripped by a cone fixed to the boring-bar; they are disengaged and the tup falls. With a 50-kilogram tup (110 lbs.) and a bore-hole 150 millimetres (6 inches) in diameter, 50 to 60 strokes per minute can be given. It is stated that an ordinary mechanical apparatus of the same size can only give 20 to 25 strokes per minute. A pressure of 10 atmospheres (150 lbs. per square inch) is needed, and at most two men are required to work the apparatus. The operating-costs are said to be small.

H. R. S.

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Sewage-Disposal at Derby.

(The Engineer, London, 28 December, 1906, pp. 651.)

The new works for the sewage-disposal of Derby were sanctioned by Parliament in 1901, and are now practically completed. The works comprise intercepting-sewers, pumping-station buildings and machinery, sedimentation-tanks, percolating-filters and storm-water overflows, with the necessary culverts, overflows, etc. Up to the present £235,000 has been expended on the works.

The existing sewers in the Borough of Derby convey sewage and the rain-water running off the roofs, yards and roads, and discharge this liquid either into culverted brook-courses which run through the town .or else direct into the River Derwent. The new scheme provides for the interception of a certain proportion of the rain-water by means of new sewers which will carry the fouled liquid down the valley to Spondon, where it will be treated bacterially. At the present time the population is about 120,000 and the water-supply less than 25 gallons per head per day. The intercepting sewers are designed of a size capable of carrying down to the overflow-chamber at Alvaston 12 times the dry-weather flow, calculated on a future population of 180,000, with a water-supply of 30 gallons per head per day. Any excess will overflow into the nearest brook or into the river in the borough. From the Alvaston overflow-chamber a 6-foot by 4-foot egg-shaped sewer conveys the sewage to the pumping-station, where the plant is capable of dealing with six times the dry-weather flow; the excess over this quantity up to 12 volumes overflows into the river at Alvaston. The pumping-plant consists of three engines, with room for a fourth, driving three-throw plunger-pumps, each capable of raising 600 cubic feet of sewage per minute from the sump to the tanks and three storm centrifugal pumps, each capable of lifting 900 cubic feet per minute from the sump on to the storm-water beds. The sewage is conveyed in covered channels to the tanks, to which its admission is controlled by valves. There are 6 tanks, each 310 feet by 37 feet, divided by cross-walls into three divisions; their total capacity is 4,320,000 gallons, and room is available for two more. At the outlet-end the effluent is withdrawn about 4 feet 6 inches below top-water level and falls over a fixed weir into a covered channel, which conveys it to the continuous filters. There are eighteen of the latter, nine on each side of a double culvert, one of which supplies the filters and the other collects the effluent; room is left for twelve additional filters. The filters are circular, each 100 feet in diameter, the average depth of the filtering material being 6 feet 7 inches. The sewage is sprinkled on their surface by revolving distributors. The walls of the filters are built of honeycomb brickwork, and the filtering material is further aerated by three tiers of perforated pipes brought to the face of the side walls. A concrete culvert conveys the effluent from the filters to the river, into which it is discharged through iron pipes controlled by valves which can be used to back

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up the effluent in the culvert to a sufficient height to admit of its being turned on to the land. The storm-water beds are seven in number, having an aggregate area of 25,100 square yards, the average depth of filtering material being 3 feet 3 inches; a by-pass pipe from the outlet-channel from the tanks permits at least 2,000,000 gallons of sewage per day being turned into the storm-water beds, which are used as contact-beds.

A. W. B.

Sewage-Irrigation at Brunswick, 1895 *to* 1900.

Prof. Dr. H. Beckurts and Prof. Dr. R. Blasius.

(Zeitschrift für Hygiene, Leipzig, vol. lv, part 2, pp. 232–94.)

It is pointed out that in consequence of the introduction of a complete system of sewerage into Brunswick, which was undertaken from the year 1870 onwards, the River Oker became more and more polluted, and it was necessary to devise means for the treatment of the sewage previous to its discharge into the river. It was at first attempted to make use of chemicals as precipitants, in connection with the Röckner-Roth system, and in 1887 an experimental station on that system was erected and remained in use for several years, but difficulties arose with the sludge and the purification was not satisfactory. It was decided, therefore, to employ broad irrigation in preference, and a property at Steinhof, with additional land, was acquired for that purpose. The drainage-works were completed about 10 years ago, and since then the whole of the sewage has been taken to the farm, by means of a cast-iron rising-main, about 4·34 miles in length, with a diameter of 31·4 inches. The total available area is 1,158 acres, the larger part of which has been adapted for irrigation, either as market-garden plots, meadows or reservoirs. A small extra amount of land belonging to private owners is likewise available, so that the entire area for the treatment of the sewage of about 100,000 persons is 1,112 acres, or about 90 persons to the acre. The average daily quantity of sewage under treatment amounts to 2,464,000 gallons, or 2,225 gallons to the acre. The general arrangements at Steinhof are explained by reference to a plan. The situation of the property and its proposed use for sewage-irrigation gave rise to violent complaints on the part of the Brunswick and Prussian authorities, and the project was only sanctioned after an enquiry conducted by Dr. Ohlmüller and Dr. Orth. It was feared that the watercourses and springs in the vicinity would be polluted by the effluent and that the works would give rise to nuisance. To guard against these dangers a very strict control was insisted upon, and the results of the investigations carried on for that purpose in the course of the first five years are contained in the present report. The sewage-water was analysed each month, and fifty-three separate analyses are tabulated, the average propor-

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tions of impurities being set forth. The river-water was also examined periodically, the results of the analyses being given. Tests of effluents and underground-water were also carried out at numerous points surrounding the works, some twelve in all, which are indicated on the map. The entire series of analyses are given in tables too lengthy to abstract, and the Authors sum up their conclusions, which are briefly as follows:—No injury has been caused to the soil, which has been found sufficient for the purpose; no nuisance has arisen from the spreading of the sewage-water over the land, and the treatment has been so satisfactory that the river was in no case found to be polluted; the water-supplies of the neighbouring villages remained uncontaminated; the agricultural produce of the farm was in all respects excellent, and the cost of treatment of the sewage-water, including outlay of every kind, has been about 11½*d.* per head of the population.

G. R. R.

Distribution of Gas at High Pressure. PAUL RAULIN.

(Le Génie Civil, Paris, vol. xlix, pp. 263–7.)

The introduction of the incandescent mantle, coupled with the great increase in the use of gas for cooking, general heating and as a source of power, has wholly altered the problem presented to the gas-works engineer, as the illuminating value of the product now takes only a second place in comparison with the calorific properties. But whatever be the nature of the product supplied, some more efficient method of distribution is needed, particularly in view of the tendency to supply much larger areas from one centre. In electrical distribution it was soon found that, in order to secure economy, wherever long distances had to be traversed, the voltage, *i.e.*, the pressure, must be raised far above that at which the current can readily be used for domestic purposes. Sub-stations are then required from which the current can be re-distributed at convenient pressure. It would appear that the same principle might be applied to the distribution of gas. The increased pressure might be obtained by compressing-pumps at the works, and reducing-valves at suitable centres might be used for transforming the pressure down to that best fitted to the needs of the consumers. Sufficient experiments have not yet been made to determine the effect of compression on gas of different qualities, but such as have been carried out point to the calorific value being rather improved than otherwise, although the illuminating properties suffer appreciably. It has been urged against distribution under pressure that (1) a small leak would result in an enormously greater loss; and (2) there would be a danger of the reducing-valves failing to act and allowing the full pressure to enter the consumers' premises. The former resolves itself into a mere matter of jointing, while the

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possibility of a failure in the reducing-valves might be overcome by placing these in duplicate, and by providing efficient relief-valves on the low-pressure mains. A description is given of a high-pressure distribution in the neighbourhood of Chicago, where the pressure is as high as 2·1 kilograms per square centimetre (30 lbs. per square inch), and the length of the system is 690 kilometres (430 miles).

I. C. B.

Generation of Suction Producer-Gas from Lignite Briquettes.

CRAYEN.

(Zeitschrift für Bauwesen, Berlin, 1906, vol. lvi, Parts x–xii, pp. 669–74.)

An account is given of a suction-gas producer plant erected at the Güsten station to furnish about 100 HP. for the generation of electricity. Large quantities of lignite are found in the vicinity, and this material is made into briquettes, and it was considered advisable to try to employ these briquettes for the preparation of producer-gas. By means of illustrations the form of producer used is explained. It consists of a vertical wrought-iron shaft, lined with firebrick, with a grate in the lower part and doors in the sides for cleaning the fires. The gas generated is withdrawn below by a pipe of a good size to moderate the draught, and at the top of the generator is a flue to carry off the smoke when the engine is not at work. Above the furnace-chamber is a fuel receptacle in which the briquettes are heated up before entering the furnace, and the form of the upper part of the furnace-chamber is slightly conical, so that if the amount of gas needed is small the zone of combustion mounts upwards to the part where the sectional area is reduced, whereas, while in full delivery, the zone of combustion sinks lower and a larger area of incandescent fuel is secured. The products of combustion and of stove-distillation are drawn down through the hot fire and consumed with the large mass of water-vapour, and provision is made for an extra air-admission in the lower part of the furnace and for steam produced in the ash-pit to rise up and enter the gas-producer. Details are given of the single-cylinder gas-engine which makes 160 revolutions per minute and furnishes 113 HP. Full particulars are appended of a 12-hours' test, working with the lignite briquettes costing 12*s.* per metric ton. The cost per effective HP.-hour varied according to load between 1·65 pfennig and 2·00 pfennig (0·20*d.* and 0·24*d.*). It is stated that for successful use in the gas-producer, it is essential that the briquettes should be small in size, as otherwise they tend to scaffold. The gas is cleansed in a coke-filled scrubber and is also passed through sawdust.

G. R. R.

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Relation of Gas-Manufacture to Coke-Oven Distillation.

Fr. Schreiber.

(Journal für Gasbeleuchtung, Munich, 27 October, 1906, pp. 925-9.)

During the distillation of coal in coke-ovens, the gases evolved pass through the centre of the mass of fuel and are not brought into contact with the highly-heated walls. By the carbonization of coal in vertical retorts for gas-making purposes, this condition is better realized than by carbonization in horizontal retorts, a higher yield of tar and ammonia is obtained, and a more solid and larger coke is produced by vertical retorts. The rapid escape of the gases from the heated area directly they are generated is essential, and the Author found that by employing two ascension-pipes instead of one to a horizontal coke-oven, the yield of ammonia calculated as sulphate of ammonia increased 0·15 per cent.

The cost of erection prohibits the use of vertical coke-ovens. The coke produced in such ovens is of a more solid nature than that produced in horizontal ovens; however, by the distillation of coal compressed to the briquette form, a coke of still greater solidity may be obtained even in horizontal ovens.

The heating-surface per unit-weight of coal is much greater in a gas-retort than in a coke-oven, which accounts for the large yield of gas and condensable products from the former, whilst the coke produced is of lower quality. However, when the manufacture of gas is the primary object, the Author considers that, taking into account the facilities for charging and discharging, and the possibility of large heating capacity, a vertical retort of similar cross-section to that of a coke-oven is the most suitable.

In order to obtain a large yield of gas it is found advantageous to carbonize a caking-coal which produces a porous coke of low density. Coke to be employed for metallurgical purposes should be hard, and such a coke is obtained by carbonizing caking-coal which has been compressed. This innovation suggests the possibility of using coal briquettes to which lime has been added, in order to reduce the quantity of volatile sulphur compounds. Older processes have failed, owing to the difficulty experienced in mixing the lime uniformly with the coal. In the case of briquettes, the lime can be mixed uniformly, and is added in proportion to the quantity of sulphur present in the coal.

An experiment was carried out with briquettes, to which 3·5 per cent. of lime had been added, with the results given on p. 491.

The addition of lime to the briquettes in this manner seems to have no deteriorating effect on the coke produced. It will be seen that the amount of sulphur present in the gas is greatly reduced, which represents a saving in the cost of purification. Again the yield of gas is slightly increased, whilst the amount of ammonia produced is about 25 per cent. higher.

The gas obtained by the distillation of coal in coke-ovens has an average composition of air, 6·20 per cent.; nitrogen, 16·11 per

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	Briquettes without Lime.	Briquettes with Lime.
Ash in coal . . . . . (per cent.)	5·24	8·74
Yield of coke . . . . . (per cent.)	68·56	69·77
Ash in coke . . . . . (per cent.)	7·43	12·60
Sulphur in coke . . . . . (per cent.)	1·03	1·36
Gas per ton of coal . . . . . (cubic feet)	11,302	12,009
Calorific power . . . (B.Th.U. per cubic foot)	545	539
Sulphur (per 100 cubic feet)—		
In crude gas as H_2S . . . . . (grains)	195·2	37·1
In purified gas as S . . . . . (grains)	27·1	7·2
Ammonia as sulphate of ammonia	0·839	1·05
Cyanogen as $K_4Fe(CN)_6$ (grains per 100 cubic feet)	120·3	88·1
Tar . . . . . (per cent.)	6·6	5·8

cent.; carbon dioxide, 4·20 per cent.; hydrogen, 42·03 per cent.; methane, 21·86 per cent.; hydrocarbons C_mH_n, 3·10 per cent.; carbon monoxide, 6·50 per cent., and a calorific value of 411 B.Th.U. per cubic foot.

The gas evolved during the earlier period of distillation is of better quality than later. The richer gas, which constitutes some 50 per cent. of the total yield, has an average composition of oxygen, 0·10 per cent.; nitrogen, 4·10 per cent.; carbon dioxide, 2·90 per cent.; hydrogen, 44·40 per cent.; methane, 37·40 per cent.; hydrocarbons C_mH_n, 5·00 per cent.; carbon monoxide, 6·20 per cent., and a calorific value of 607 B.Th.U. per cubic foot. This gas is suitable for sale, whilst that generated at a later period of distillation may be used for heating the furnaces.

In conclusion, the results obtained by the distillation of coal in coke-ovens are given:—

	Percentage of Dried Coal.
Coke	72·72
Volatile matter	27·28
Tar	3·77
Ammoniacal liquor	6·75
Benzene	0·881
Sulphuretted hydrogen	0·285
Carbon dioxide	1·425

The yield of free and fixed ammonia calculated as sulphate of ammonia was 0·991 per cent.

One ton of dried coal yields 10,950 cubic feet of gas of the following composition:—

	Per Cent.
Nitrogen	3·87
Carbon dioxide	0·30
Hydrogen	52·15
Methane	30·27
Hydrocarbons C_mH_n	4·88
Carbon monoxide	8·53

and of a calorific value of 551 B.Th.U. per cubic foot.

E. V. E.

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Rendering Water-tight a Masonry Gasholder-Tank.

M. G. DESPIERRE.

(Proceedings of the Société technique de l'Industrie du Gaz en France, Paris, June, 1906.)

For a long time it had been noticed that a gasholder-tank, about 50 feet in diameter, was leaking slightly, but the loss of water was insignificant. However, in the spring of 1905 numerous fissures made their appearance in the tank, due probably to the thaw, and the loss of water amounted to over 4,000 gallons per day. Owing to the scarcity of water which usually occurs in the district during the summer months it was evident that the leakage would have to be remedied at once, and it seemed probable that the masonry tank would have to be replaced by a cast-iron tank, although the cost would amount to about £1,650. The idea of binding the tank by steel-wire ropes, set whilst hot in order to close the fissures, appeared favourable, and the project was put in operation in June, 1905.

The tank was first emptied and the cracks well filled with cement, a ring consisting of two steel-wire ropes was placed round the tank about 5 feet below the coping stone. Each rope was composed of fifty steel wires about ¼-inch in diameter. One end of the rope was made fast to the tank whilst the other was coupled to a strong tackle. Cramping-irons were inserted into the masonry of the tank below the rope, and on these a gallery was built which served to hold the incandescent coke and wood-charcoal.

On warming the wire-rope, which was about 180 feet long, a lengthening of 2 feet 6 inches was attained. The extremities of the rope were fastened together whilst hot and immediately covered with cement. A second ring was set about 6 feet below the first. Several H-iron girders were placed vertically between the wire-rope and the tank for strengthening purposes, and the whole was covered with cement. After a few days the tank was filled with water.

A year has elapsed since these repairs were carried out, and neither can any fissure be seen in the masonry nor is there any leakage of water. Moreover, the cement covering the steel-ropes and uprights has not cracked.

The total cost of this work was only £60.

E. V. E.

Advantages of Mechanical Retort-Stoking. LUBSZYNSKI.

(Journal für Gasbeleuchtung, Munich, 18 August, 1906, pp. 700–1.)

The Author states that he has employed West's charging- and drawing-machines for 3 years with very favourable results. He is in a position to compare mechanical-stoking with hand-stoking, as in 1902–3 all the retorts were charged by hand, whilst in 1904–5 all charging was executed by West's machines.

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The working results are shown in the following Table:—

No.		1902–3	1904–5
1	Yield of gas . . . . (million cubic feet)	358½	384
2	Consumption of coal . . . . . (tons)	34,845	35,386
3	Average make per ton of coal . (cubic feet)	10,284	10,854
4	Yield of gas per day and retort . (cubic feet)	8,102	8,210
5	Average retort charge . . . . . (lbs.)	442	425
6	Maximum number of workmen in January .	170	70
7	Average number of settings at work . . .	13·59	14·46
8	,, ,, ,, retorts ,, . . .	121·71	128·28
9	Cost of working	£8,255	£4,398

The higher yield of gas is due to the fact that the doors are not allowed to remain open so long as with hand-stoking, and also that the retorts are much more uniformly charged by machines. The working-expenses were reduced by £3,857 during 1904–5, and at the same time an increased yield of 25½ million cubic feet was obtained.

The following Table is given in order to show the advantages from a financial point of view:—

	£		£
Saving of expenses	3,857	Gas-consumption for driving-engines for the year 1904–5 = 6¾ million cubic feet.	
By higher yield—		This at 1·24*s.* per 1,000 cubic feet	417
1902–3 = 10,284 c. ft. per ton		12 per cent. to writing off capital account and for depreciation	1,800
1904–5 = 10,854 ,, ,, ,,			
Equivalent to 1,956 tons of coal less carbonized.			2,217
This at an average price of 14*s.* 5*d.* per ton	1,412	Total saving	3,052
	£5,269		£5,269

From these figures it is seen that an actual saving of about £3,500 is realised, and this amount has essentially improved the financial return of the works. Thus, during last year, 1905–6, with a production of gas amounting to 388½ million cubic feet, a profit of £28,000 was realised after allowing £15,800 for writing off capital account, interest, etc.

Notwithstanding these advantages the men are more contented and their standard of health is higher than with the old system of hand-charging.

E. V. E.

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Automatic Charging of Horizontal Retorts. A. Cabrier.

(Proceedings of the Société Technique de l'Industrie du Gaz en France, Paris, June, 1906.)

The Author has constructed a shoot by which retorts may be automatically charged with coal. A quantity of coal is allowed to fall from an overhead hopper on to a shoot consisting of a smooth grooved surface of sheet-iron set at an incline to the falling mass and with its delivery-end curved abruptly towards the mouth of the retort; the direction of the falling coal is thus changed from the vertical to the horizontal.

The force of the falling coal is a function of the mass and the velocity. The mass varies with the area of the mouth of the hopper, whilst the velocity varies with the position of the shoot. By conveniently proportioning the one to the other the falling coal may be shot to the back of an ordinary retort, and will bank up until it is uniformly charged.

The projector runs on a frame in front of the retort-bench and carries one shoot for each tier of retorts. These shoots may be adjusted so as to vary the angle of the inclined surface receiving the coal from the hopper, in order to allow an alteration in the quantity of coal to be charged into the retort.

One hopper is required for each retort, and these small hoppers are placed together on a stage above the charging-floor of the retort-house. In the experimental installation the hoppers were about 19 feet 6 inches above the ground floor. The time required to charge a retort 10 feet long is 4 to 6 seconds; the projectors, however, are arranged, with two or three shoots, according to the number of retorts in the vertical line, in order that more than one retort may be charged at a time.

A sketch is shown of the form of shoot best adapted for projecting coal into the retort employed.

E. V. E.

Inverted Burners. H. Süssmann.

(Journal für Gasbeleuchtung, Munich, 22 September, 1906, pp. 826–30.)

The Author, in discussing the principles involved in the construction of inverted burners which are to be found on the market at the present day, states that in some cases the mixture of gas and air to be conducted to the burner is kept as cool as possible, whilst in others the gases are heated before combustion. At first it would appear that the regeneration of heat, by producing a greater flame-temperature, would be advantageous, but experiments prove that this is not the case. It is well known that if the tube of an ordinary upright Bunsen burner be heated, the effect produced is to gradually increase the size of the inner cone until ultimately the flame

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becomes luminous and quite unfit for heating an incandescent mantle, and it is to be remarked that the lower the pressure of gas the smaller will be the amount of heat required to produce a luminous flame. If this burner be inverted, the tube will be heated not only by the flame but to a much greater extent by the uprushing warm products of combustion. In the case of the upright burner, by heating the tube, the flow of the rising mixture of gas and air is increased, but when the burner is inverted this force acts in a direction which retards the flow of the mixture to the orifice of the burner. The retardation of flow will also have the effect of reducing the quantity of primary air aspired by the burner, with a consequent reduction of flame temperature. As the tube of the inverted burner becomes heated the quantity of air aspired varies, and the adjustment made to produce the light of maximum intensity when the burner is lighted has to be altered after some minutes of burning; the burner therefore which shows the least variation in air-supply when the tube is cold and when hot possesses the greatest advantage in this respect.

If the pressure of gas to an inverted burner is low and the tube of the burner is strongly heated, the retarding force produced is so great that the burner is unworkable. The aim of the inventor should be to insulate the tube conducting the mixture to be burnt, and to remove the heated products of combustion as quickly as possible.

In some of the modern inverted burners the mixing-tube is increased in diameter towards the orifice of the burner in order to allow the gaseous mixture to expand as it becomes heated. With this form of burner the maximum quantity of air in the mixture is assured, moreover a very steady flame is produced which is not sensitive to vibrations.

E. V. E.

Radiation of Incandescent Mantles. Foix.

(Comptes Rendus de l'Académie des Sciences, Paris, 1907, vol. cxliv, pp. 685-7.)

The addition of traces of cerium oxide to an incandescent mantle of thorium oxide increases very largely its luminous radiation without modifying the infra-red radiation. The Author investigates the cause of this phenomenon and shows that the luminous emissive power of an oxide-of-thorium mantle is zero, while that of a cerium-oxide mantle is almost unity. Oxide of cerium has high absorbing power, especially for luminous radiations. When cerium oxide is added progressively to thorium oxide, the absorbing power of the mixture is increased in proportion to the oxide added, and hence the light transmitted by the mixture soon becomes negligible. Some disadvantages inherent in the thorium mantle might be avoided by increasing the percentage of cerium oxide, but this is not done, as the essential condition for good luminous emission is the conservation

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of the high temperature of incandescence (1,530° C.) of the thorium-oxide mantle. This high temperature is due to the low total emission of the thorium oxide, an emission which is primarily infra-red. The mixture in the Auer mantle must therefore have practically the same infra-red emission; but as a cerium-oxide mantle, made like the Auer mantle with 25 per cent. solutions of the nitrate, has ten times the infra-red radiation of a thorium mantle, 1 per cent. of the former substance added to the latter gives the same result. The luminous radiation of cerium-oxide would be increased by diminishing the thickness of the radiating mass without diluting it.

Theoretically, therefore, the thorium oxide is useless, but practically it is indispensable, as it supplies a frame-work for the cerium-oxide, which, in the pure state and in very thin layers, would be too fragile if used by itself.

W. C. H.

Electric Automobiles. R. DE VALBREUZE.

(L'Éclairage Électrique, Paris, 1907, vol. 1, pp. 116–32.)

In a former article[1] the Author outlined the different methods of propulsion adopted for electric automobiles, dividing them for this purpose into two classes—those with two motors and no differential gear, and those with one motor and a differential gear. In the present article, adopting the same classification with various sub-divisions in each class, the Author gives a rapid survey of the different mechanical and electrical solutions adopted by the different makers, describing and illustrating a large number of cars. In the changes introduced in the last two or three years in the construction of these vehicles two things are apparent—(1) the favour shown by various makers to the system of transmission by a longitudinal cardan-shaft, and (2) the suppression in a large number of cars of the elastic suspension of the motors, which bear all the shocks and jolts to which the wheels are subjected.

W. C. H.

Petrol-Electric Vehicles. R. DE VALBREUZE.

(L'Éclairage Électrique, Paris, 1907, vol. 1, pp. 263–76.)

This article gives a classification and detailed description of the different types of vehicle which are propelled by a combination of a petrol-engine with various electrical devices fulfilling different functions. There are three classes in the Author's classification:—

[1] Minutes of Proceedings Inst. C.E., vol. clx, p. 456.

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(1) Vehicles having a dynamo mounted as fly-wheel on the explosion-engine and connected to a battery of accumulators, this dynamo acting sometimes as generator, sometimes as motor, either to use the surplus power of the heat-engine when the resisting couple is small, or to come to its aid when that couple is large; (2) Vehicles in which the heat-engine drives a generator, directly mounted on the shaft, while the dynamo in turn supplies current to electric motors driving the wheels; (3) Vehicles in which the electrical part of the equipment only replaces the ordinary mechanical arrangements for changing speed. A large variety of vehicles is considered in each class, the most prominent types being illustrated and explained in detail.

W. C. H.

Condensers in Distribution-Systems. C. F. GUILBERT.

(L'Éclairage Électrique, Paris, 1906, vol. xlix, pp. 441–51.)

In this article the Author gives a mathematical discussion of the influence of condensers on the higher harmonics of the curve of electromotive force in distribution-systems. The case of a condenser in parallel with a distribution-system without capacity of its own is first discussed, and the analysis is then extended to the case of a system having capacity uniformly distributed. The Author shows that the only case where resonance can be avoided and where the higher harmonics of the pressure are reduced by the capacity, is that in which use is made of concentric cables, that is to say, of cables without appreciable self-induction.

W. C. H.

Electrolytic Rectifier of Alternating Currents.

J. A. MONTPELLIER.

(L'Électricien, Paris, 1907, vol. xxxiii, pp. 128–33.)

The Author describes an electrolytic rectifier of alternating currents which is based on the experimental fact that if a current is passed into an electrolyte by electrodes, one of which is of lead and the other of aluminium, the current passes freely when the aluminium is the cathode, but is stopped when the aluminium is the anode. In the new rectifier the electrolytic cell consists of a cylindrical vessel containing a solution of sodium phosphate, and having an aluminium rod at its axis, as one electrode, while the other consists of a tube of lead surrounding the axis. This tube has a series of perforations round its circumference near the foot and another at the free surface of the electrolyte, so that by the heating effect of the current a circulation of the electrolyte is set up, upwards within the lead tube

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and downwards outside it, thus preventing an objectionable rise of temperature.

The rectifier contains four of these cells, so connected as to make use of the alternating current thoughout its whole period. The Author describes the procedure to be followed in forming the cells and in attending to them when cleaning is necessary. One of the principal applications of this rectifier is the charging of accumulators, as it may be applied at will to charge, from an alternating circuit, either the whole battery for a motor-car or merely the two cells for the sparking coil, without the usual loss of energy in rheostats. In this operation a small transformer—step-up or step-down, according to the number of cells to be charged—is placed with its primary in the alternating circuit and its secondary connected to the rectifier. The apparatus may also be applied to arc-lamps, to direct-current motors on alternating circuits, and to many other purposes in electrical work. The article contains an illustration of the apparatus and diagrams of connections for the formation of the cells and for the charging of accumulators.

W. C. H.

Leakage to Earth of Electric Currents in Barcelona.

J. DE GUILLEN-GARCIA.

(Revista de Obras Publicas, Madrid, vol. liv, p. 430.)

The Author quotes the experience of engineers in the United States as to the great damage done to metallic pipes laid near tramways where leakage of electric currents is considerable. He also states that Mr. E. Guarini has proved that a flow of $\frac{1}{10}$ of an ampere would destroy 2·2 lbs. of lead in 3 months and 2·2 lbs. of iron in a year. In Barcelona there are leakages from the tramways and from the neutral cable of the power and light circuits. The Author describes the method employed by him for testing the amount of the leakages, which was taken between two points situated on a line at right angles to the tramlines and repeated in many places. Afterwards tests were made in private houses by joining pipes belonging to different companies with a wire having a galvanometer in circuit. In a certain house a maximum of 30 milliamperes was found, and in other houses currents of only 3 milliamperes. The galvanometer used had a resistance of 9 ohms. The Author made numerous tests in his house by connecting a gas-pipe belonging to Lebon and Company with one belonging to the Catalan Company, and an electric current was observed which flowed from the latter pipe to the former, as the mains of the latter company are laid bare in the ground, and those of the former have an insulating covering. The Author also investigated the leakages from the telegraph-wires by means of the telephone, and also the fluctuations of the leakages during different hours of the day. He has prepared curves showing

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the fluctuations of the leakages for 24 hours for ordinary days, and also for festivals, when the trams were not in use, thus enabling the leakage from the tramways to be separated, and he desires to induce the Corporation to continue these tests, as he believes the results of the leakages will be serious.

E. R. D.

Design of Induction-Coils. W. O. Eddy and M. Eastham.

(Electrical World, New York, 1906, vol. xlviii, pp. 1197-1201.)

In this article the Authors discuss the problems which have to be considered in the design of that class of induction-coils which is used in connection with the transmission of wireless-telegraphy signals or in the generation of Röntgen-rays. The essential parts of the coil are discussed separately and with regard to their relations to one another—the core, the primary coil, the insulation and insulating-tube, the secondary coil and the condenser. From theoretical and experimental considerations the Authors draw conclusions having an important bearing on the mechanical and electrical construction of these coils.

W. C. H.

Autographic High-Speed Telegraphy. A. C.

(Le Génie Civil, Paris, vol. l, pp. 216-9.)

The apparatus invented some years ago by two Hungarian engineers, Messrs. Pollack and Virag, has latterly been greatly modified, with the result that the speed of transmission has been increased to 40,000 words per hour, and the writing made so legible that the paper band as removed from the receiver can be forwarded, as it stands, to its destination, no transcribing being necessary. The transmitter consists of a drum, round which a perforated band of paper is made to pass, the position and size of the perforations regulating the message to be sent. This drum is built up of six metal rings placed side by side and insulated from each other. A brush sweeps over the outside of the perforated band and comes in contact with such of the metallic rings as are for the instant exposed through the perforations in the band. When the brush is in contact with any one of the three rings composing half the drum, a current is sent to the receiving-station through a pair of conductors, which, acting through the intermediary of an ordinary telephone-receiver, can deflect a mirror through an extremely minute angle about a vertical axis; while, when the brush is in contact with any one of the other three rings, a current is sent through another pair of conductors capable of deflecting the same mirror about a horizontal axis. Of the three rings in each set one

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transmits a current of 10 volts, and another of 5 volts, while the remaining one transmits a current of 10 volts in the opposite direction; thus by each set the mirror can be deflected, strongly in one direction, slightly in the same direction, or strongly in the opposite direction. A spot of light reflected from this mirror is made to focus on the receiving-band of paper which is photographically sensitive, the whole receiver being enclosed in a light-proof box. The two motions of the mirror when compounded cause the spot of light to trace the characters on the sensitized band in a legible running-hand. The machine for perforating the transmitting-band takes the form of a typewriter, and on the depression of any key a series of perforations is made which corresponds with the letter on the key. Iron, as might be expected, is unsuitable for the line-wires, and precautions have to be taken in the case of long lines and high resistances, otherwise the writing will become deformed. The apparatus has been in use between Budapest and Pozsony, a distance of 218 kilometres (135 miles), and more recently has been tried between Paris and Lyons, a distance of 520 kilometres (323 miles). In both cases it has been found wholly successful.

I. C. B.

Hydraulic Compressed-Air Power-Plant. D. E. Woodbridge.

(Engineering and Mining Journal, New York, 19 January, 1907, p. 125.)

A skilful adaptation of an old method of air-compression, now in successful operation at the Victoria Mine and Mill, Ontonagon County, Michigan, is attracting much attention on the part of the users of power. This is not surprising when it is stated that more than 82 per cent. of the actual power of the water is transferred to compressed-air under a pressure of 117 lbs. without any moving machinery and delivered to the air-main dry and at the temperature of the water, at a cost of about 9*s.* per HP. per annum. The plant was designed under a guarantee to develop 4,000 HP. with an efficiency of 70 per cent.

Water is taken from the Ontonagon river, by means of a dam and a canal, and returned to it a mile down stream, after the benefit of a net fall of 71 feet has been secured. At the foot of the canal three vertical, circular and smoothly-cemented shafts, 5 feet in diameter, were sunk 330 feet, ending in the roof of a large chamber. Down into this chamber, continuing the shafts for a length of 16 feet, project conical steel tubes, which flare to a diameter of 7 feet 4 inches at the bottom; these are set above concrete spreading-piers built on the chamber-floor. This chamber, into which the water from the canal falls, is at this part 57 feet wide by 22 feet high. These dimensions are continued for 50 feet, beyond which point the chamber narrows to a width of 18 feet and a height (to the centre of its arched roof) of 25 feet. These dimensions are continued till a total length of 282 feet is reached. From this point the chamber

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becomes a tunnel, having a height of 10 feet, and continues as such 40 feet farther, where an inclined shaft to surface carries the water back to the river. It is in this underground chamber, excavated in rock, that compression takes place. The air-pressure head is 261 feet and the air-capacity of the chamber, between its water-line and roof, is 80,264 cubic feet.

Briefly the action of this plant is as follows:—On the bottom of the forebay are the upper ends of the three cylindrical shafts, each in a steel tube rising 6 feet above the bottom of the bay. In this, and forming its upper movable end, is telescoped an additional length, which moves freely up and down, so that it may be in any depth of water or above the water to stop the action of the plant. Above this is an annular pipe or "header," intended to be below the water-level when the plant is in action. This header, of an average diameter of 10 inches, is directly connected with two sets of tubes, one of which consists of eight 7-inch verticals with the upper end projecting above the water-line. These are the air-intakes. There are 1,800 $\frac{3}{8}$-inch tubes projecting inward horizontally from the header. Over these water flows downward and by its suction draws air down the atmospheric intake, through the small tubes and into the column of water descending the main shaft to the compressor-chamber. When, by means of a capstan, the headpiece is lowered till the upper conoid casting is a few inches below the water-level in the bay, the water rushes in between the mass of $\frac{3}{8}$-inch air-tubes. After passing the end of the small air-pipes, the water begins to fall away with increasing velocity, causing a partial vacuum to be formed, thereby drawing the air through the tubes and enclosing small bubbles in the descending water, and, carrying them down the shaft, gradually compresses them, taking up at the same time the heat of compression. At the lower end of the shaft the mixed volume of air and water is spread out in all directions by the conical cement pier and flows slowly along the separating-chamber to the outlet-tunnel and shaft. The air rises through the flowing water and accumulates in the dome of the chamber.

So great is the compressing-capacity of these works, more than 36,000 feet of free air per minute, that air may be drawn off at the rate of 72,000 cubic feet per minute for 18 minutes without causing a drop in pressure of more than 5 lbs. The Author gives several illustrations to show details of construction.

G. G. A.

Large Hydraulic-Power Plant.

(Engineering and Mining Journal, New York, 2 February, 1907, p. 240.)

The Stanislaus Electric Power Company is about to instal near Angles Camp, California, an electric power-transmission system involving the largest impulse-wheels yet built. The scheme is for utilizing the waters of the Stanislaus river, transmitting the power

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electrically to San Francisco, and, incidentally, tapping the southern mines and the upper San Joaquin valley.

The effective head is 1,400 feet, equivalent to a pressure of 608 lbs. to the square inch. The equipment will include three 6,700-kilowatt General Electric Company's generators, making 400 revolutions per minute, each of which will be driven by a Pelton water-wheel unit of 1,200-HP. capacity. The units for this plant will be of the "double overhung" construction, each unit consisting of two Pelton wheels overhanging the ends of a heavy shaft carrying the rotor of the generator in the centre. Each wheel will consist of a cast-steel annealed disk-centre to which the Pelton buckets, also of cast-steel, are to be attached. The shaft will be fluid-compressed, hollow-forged, nickel-steel 28 feet in length and 20 inches in diameter at the centre where the rotor is placed, and 16½ inches at the water-wheel journals. The wheels and rotor will be designed for a press-fit on the shaft at 100 tons pressure. The journals, one on each side of the generator, will be larger than any hitherto designed for this class of work, being 16½ inches in diameter by 60 inches long. They are to be of the ring-oiling, ball and socket type, water-jacketed and provided with an oil-pressure and gravity-feed lubricating-system. There will also be electric thermostats and indicators to give warning of excessive heating. The nozzles will be of the needle-deflecting type, admitting of close regulation and water-economy. These, like the gate-valves, will be of steel. The gates, nozzles and needles will be under the immediate control of the station attendant at the switch-board, small Pelton motors and direct-acting plungers being provided for this purpose.

G. G. A.

River Pescara Hydraulic-Electric Installation.

(Il Politechnico, Milan, November, 1906, vol. liv, pp. 607-11.)

A supply of water is obtained from the River Pescara for the transmission of electrical energy for lighting and power purposes. The total fall of 99·2 metres (325 feet) is divided into two sections, the first, which is here described, having a fall of 27·6 metres (90 feet), and developing 8,400 HP., and the second a fall of 71·6 metres (235 feet), with an output of 22,000 HP. The water consumption is 30 cubic metres (6,600 gallons) per second. A dam is constructed across the river, from behind which the water is drawn off through a series of hand-regulated sluices, and after passing through a screen enters the feeding canal. This latter has a total length of 2,572 metres (2,800 yards), and for a length of 2,235 metres (2,400 yards) is in tunnel through the side of the mountain bordering the valley of the Pescara. This tunnel has a gradient of 1 in 1,250, with a sectional area of 17·4 square metres (187 square feet), and has its outlet into a discharge-chamber, from which the water is taken to the turbines driving the main gene-

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rators through four iron tubes, each 2·2 metres (7¼ feet) in diameter, and for the exciter-turbines through one tube 0·6 metre (2 feet) in diameter.

The generating-plant consists of four sets of turbo-alternators, each of 2,800-HP. capacity. The turbines are horizontal turbines of the Francis type, and are provided with automatic regulators. They are designed to give an output of 2,800 HP., with a fall of 27·5 metres when running at 270 revolutions per minute. The current is generated at a voltage of 6,000, with a frequency of 45 cycles per second. The exciters consist of two turbine-driven dynamos, each of 150-HP. capacity, at a speed of 400 revolutions per minute. One main set and one exciter set constitute a reserve. Three main overhead lines are supplied from this station, two being at 6,000 volts pressure, and the third and largest at 25,000 volts. The transforming-plant for this line consists of four (one reserve) step-up transformers, each of 150-kilovolt-ampere capacity, coupled together to give a three-phase transformation of 450-kilovolt-amperes.

The article is illustrated by several plans and photographs.

L. F. M.

High-Tension Direct-Current Transmission at Lyons.

J. Reyval.

(L'Éclairage Électrique, Paris, 1907, vol. l, pp. 13-18 and 46-51.)

In order to meet the growing demand for electric power at Lyons and in the neighbouring districts, where a three-phase system is already installed, a new installation has recently been laid down by which power is generated at Moutiers in Savoy and transmitted to Lyons—a distance of 108 miles—by high-tension continuous currents on the Thury system. The energy is generated in the form of continuous current of constant intensity (75 amperes) and of high pressure (60,000 volts). This current is brought by overhead wire to a point close to Lyons, where part of the energy is converted into three-phase currents to serve the existing three-phase network, while the remainder is led by underground cables to a sub-station in Lyons, where the pressure is reduced to 600 volts for traction. For future extensions of the system it is proposed to raise the transmission-pressure still higher by having a neutral point connected to earth at the middle of the winding of the generators; by this means the pressure might be raised to 150,000 volts, the difference of potential between one wire and earth being 75,000 volts.

Power at the generating-station is derived from a waterfall on the River Iser, 215 feet high. There are four turbines, each giving 1,570 HP. at 300 revolutions per minute. Each generator consists of four dynamos arranged in pairs on the same bed with a common shaft, and the turbine is mounted between the pairs and coupled to

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them by two elastic and insulating couplings of special form described in this article. There are thus sixteen dynamos forming four generators, the pressure at the terminals of each generator being about 14,500 volts, or 58,500 volts for all the generators in series. For a constant current of 75 amperes this gives a total power of over 4,400 kilowatts. The construction and the dimensions of these machines and the special arrangements for insulating them from the ground are fully described by the Author. Each double machine is fitted with an apparatus, controlled by a cam, which puts the machine in short-circuit if it should tend to run as a motor in consequence of a false operation. A distribution-pillar carries the ammeter, voltmeter and automatic cut-out for each machine, and has at the top two lightning-arresters of the magnetic blow-out type connected to the two poles of the machine. Control is provided by varying the speed of rotation of the turbines by means of servo-motors, which are in turn controlled by a special mechanism, of which the function is to keep the current constant at 75 amperes. The little motor which operates this regulator is branched on a shunt interposed in the series-circuit and takes about 6 volts. The regulator is described and illustrated, and the first portion of the article ends with a description of the arrangement of lightning-arresters for the protection of the station against atmospheric discharges, and a diagram showing the different connections in the generating-station and on the transmission-line. The second part gives a full description, with diagrams, of the transmission-lines above and below ground, and of the installations and connections at the two receiving-stations, one in Lyons where the high-pressure continuous-current is converted into low-pressure continuous current, the other some little distance from Lyons, where the conversion is to three-phase current.

W. C. H.

Laws of Proportioning Concrete.

WILLIAM B. FULLER and SANDFORD E. THOMPSON.

(Proceedings of the American Society of Civil Engineers, New York, vol. xxxiii. pp. 222-98.)

The results of some experiments on the strength and density of concrete, carried out by the Aqueduct Commission of the City of New York, are discussed in this Paper, in which also the method of testing is described. The experiments were carried on at Jerome Park reservoir, where a large amount of concrete construction was being done by contract for the Commission. Trials were made to determine the proportion of the aggregates in the concrete for maximum density and minimum porosity. These results are plotted as curves, the co-ordinates of which represent the diameters of the particles and the percentage by weight smaller than given diameters. The general form of the curve is elliptic near the origin with a

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straight line tangential to it for the large size aggregates. It was found that concrete made with graded stone having a diameter of $2\frac{1}{4}$ inches is denser than with 1-inch stone, and this is denser than with $\frac{1}{2}$-inch stone. The concrete was made up with 10 per cent. by weight of cement to the total dry material. The constants in the equation for the ellipse were determined from the experiments, so that the curve could be readily plotted from the equation.

A series of tests was carried out on concrete beams 6 inches by 6 inches by 72 inches, made up of varying proportions of cement, sand and crushed stone, and of consequently varying density. These tests disclosed the transverse and compressive strength of beams composed of different mixtures, and from the analysis of the results several conclusions are drawn. With the same percentage of cement in a given volume of concrete, the densest mixture, irrespective of the relative proportions of sand and stone, was in general the strongest.

Further, there is a certain mixture of sizes of grains of the aggregate, which, with a given percentage of cement by weight to the total aggregate, will give the highest breaking strength. The Paper is illustrated by numerous curves and photographs of the apparatus employed.

R. S. B.

Mechanics of Reinforced Concrete. C. B. Wing.

(Journal of the Association of Engineering Societies, New York, February, 1907, pp. 49–71.)

In this Paper the Author develops formulas for the design of reinforced-concrete beams, shows how they may be applied, and compares the results obtained by the formulas with the results of tests. The formulas are derived by the ordinary principles of flexures in beams, and the unit-stress in the steel is n times the unit-stress in the concrete surrounding it, where n is the ratio of the respective moduli of elasticity of metal and concrete. Thus, for ordinary tension, where P is the total load carried by the bar, A_c the area of concrete, A_s the area of metal, and S_c the unit-stress in the concrete,

$$P = (A_c + n A_s) S_c$$

The total moment of resistance of a beam M is found to be—

$$M = S_c b d^2 \left[\frac{f^3 + 1}{3 (f+1)^2} + \frac{(1-k)(f-1)}{2 (f+1)} \right]$$

in which f is the ratio of maximum compressive unit-stress of concrete to maximum tensile unit stress and b and d the width and depth of beam respectively. This equation is similar to the ordinary flexure-equation for beams, and the tensile strength of the concrete

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is regarded as offering resistance to the bending-moment. From these two equations sections of beams are calculated and the results compared with tests made by Professor Talbot of the University of Illinois.

A study of the tests shows that the value of n is about 7·5, and tests of plain concrete beams give S_c = 370 lbs. as the average value of the modulus of rupture of the concrete as determined by the ordinary theory of flexure. The computed results for centre load at the point of failure of the concrete in tension agree fairly well with the results of experiments out of 19 beams tried.

The lack of agreement, in the Author's opinion, is due to the fact that even at the point of rupture of the beam there is a part of the concrete in tension. Mr. Considère takes the total tension in his formula as $S_c\ bx$, which would be the same as the Author's if it were $\frac{1}{2}\ S_c\ bx$. These formulas do not vary materially from others which have gone before, but in conjunction with the tests they show what may be expected from formulas based on the assumptions usually made in calculating the strength of reinforced-concrete. The Paper is illustrated by plotted results of tests and calculations.

R. S. B.

Test of Bond between Concrete and Steel. T. L. Condron.

(Railway Age, 29 March, 1907, pp. 544-6.)

This article is chiefly composed of tables of results of experiments, a valuable novelty in them being the details of the slip of the steel under increments of stress. The concrete was carefully hand-mixed 1 : 2 : 4 limestone, ½-inch gauge, without dust, fairly wet, 25 days old, for the 8-inch and 16-inch embedments, and 31 days for the 12-inch, 20-inch, and 24-inch embedments. The shapes of the steel tested, as given in the first table, were round, square, twisted 2·3 twists per foot, twisted 2·8 twists per foot, Thacher type, and corrugated (new style and old), the cross-sectional areas varying 0·378 square inch to 0·424 square inch, and the perimeters 2·17 inches to 2·60 inches. Table II gives stress in lbs. per square inch of cross-section for 8, 12, 16, 20 and 24 inches of embedment, and the corresponding slip in each case of $\frac{1}{1000}$ inch, $\frac{1}{3000}$ inch, and $\frac{1}{1000}$ inch. In Table III are similar results per square inch of embedded surface. Table IV gives relative strength of bond by which, taking round bars as unity, Thacher bars average 2·22, and corrugated 2·70 to 2·95, according to pattern.

The results are also shown graphically as regards embedments of 16 and 24 inches in two diagrams.

C. O. B.

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Tests of Reinforced-Concrete Beams.

(Railway and Engineering Review, Chicago, 22 September, 1906, pp. 728–31.)

In a series of tests of reinforced-concrete beams carried out at the University of Michigan in April and May 1906, seven beams were tested, four on a span of 12 feet, two on a span of 17 feet 8 inches, and one on a span of 21 feet 8 inches. The four smallest beams were 12 inches wide, 16 inches deep and about 14 feet long. Two of these beams were reinforced with Kahn bars and the other two with plain round rods for comparison. The two longer beams for the span of 17 feet 8 inches were each 16 inches wide, 20 inches deep and 18 feet 8 inches long, and were reinforced with Kahn bars. The largest beam for the span of 21 feet 8 inches was 2 feet deep by 20 inches wide, and 22 feet 8 inches long, and also was reinforced with Kahn bars. The span in each case was clear and was kept constant by steel rollers between the supporting-blocks and the underside of the beam. In those beams which were reinforced with plain round rods some of the latter were turned up at the ends to provide against shear. All the beams were reinforced both at the top and the bottom. The tension-reinforcement varied between 1·08 and 2 per cent. of the area above the centre of steel, while the area of steel in the compressive part of the beams varied between one-third and one-half of that in tension. The beams were made in December, 1905, and were tested at the age of 4 to 5 months. The proportions of the concrete were 1 part of cement, 2 parts clean sand, and 4 parts of crushed limestone broken to $\frac{3}{4}$ of an inch and under. The moulds were very tight, a wet mixture was used, and the resulting concrete was very dense and uniform. Precautions were taken to prevent frost injuring the beams. The method of loading was devised to secure the nearest possible approach to a uniformly-distributed load, and, from the description given, it is very clear that the method was successful to an unusual degree. The method of loading was also such that there was no possibility of any arching effect taking place, and the various sections of the loading were perfectly free from each other, and not touching. The deflections were measured by means of an apparatus which gave readings of $\frac{1}{1000}$ of an inch. The method of reading and the arrangement of the deflection-recorder are clearly shown in the illustrations and figures in the text. Detailed particulars of the reinforcement and the results of the tests are given in the table, and the method of computing the probable tensile stress in the steel is described. The largest beam, that which was tested on an effective span of 21 feet 8 inches, only failed on the load reaching the figure of 136,740 lbs. inclusive of the beam's weight of 10,000 lbs., and the bending moment at the centre of the span at failure amounted to 4,442,000 inch-lbs. The steel in the tension side of this beam amounted to 1·08 per cent. at the centre of the span, while the percentage at the same section on the compressive side of the beam was 0·6, both percentages, with regard

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to the area of section of beam, being included between the centre of the tensile reinforcing steel and the top surface of the beam. The article is illustrated by twenty figures and diagrams, and there is also a table summarizing the results.

J. M. M.

Concrete-Column Tests at Watertown Arsenal.

(Railway and Engineering Review, Chicago, 21 July, 1906, pp 545–8.)

This article describes a series of tests carried out on ninety-nine concrete columns, both plain and reinforced, at Watertown Arsenal. Two tables accompany the paper—No. 1 giving the results of tests on forty of these columns, and No. 2 describing the reinforcement of the columns given in No. 1. The columns were made of different mixtures, ranging from neat cement to very lean proportions. The reinforcements included longitudinal rods and angles embedded in the columns, external reinforcements of hoops and other means, and various types of special reinforcing materials. Tests were also made on combined reinforcements of longitudinal bars and external hoops. In general the columns were 8 feet in height and 10 to 12 inches in diameter. They were tested in a horizontal position. The method of testing was as follows:—The columns were loaded by increments of 50 lbs. per square inch, the amount of compression under each increment was measured, the initial load was returned to, and the setts were measured. Micrometer observations were thus made on a gauge-length of 50 inches equidistant from the ends of the columns. Several diagrams are given illustrating results of these tests. The diagrams show the extent to which columns of various mixtures are strengthened by reinforcement. It was found that lean mixtures are strengthened in a much greater proportion than are rich mixtures. One series of tests showed that the addition of 2 parts of stone to a mortar of 1 part cement to 1 part sand (reinforced) resulted in the reduction of the ultimate strength from 5,980 lbs. per square inch to 5,433 lbs. per square inch. This loss of strength on addition of stone was not peculiar to these examples, but occurred in several cases. The results of a series of tests on a 1 : 2 : 4 mixture, the reinforcing circumferential hoops being 1·5 inch by 0·12 inch with lapped riveted joints, and the longitudinal reinforcing-angles 1 inch × 1 inch × $\frac{1}{8}$ inch, were as follows:—

Plain column (not reinforced)	1,413	lbs.	per	sq.	inch,	age	5	months	and	16	days.
13 hoops	2,232	,,	,,	,,	,,	,,	6	,,	,,	6	,,
13 hoops and 4 angle-bars .	3,029	,,	,,	,,	,,	,,	6	,,	,,	7	,,
25 hoops	3,428	,,	,,	,,	,,	,,	6	,,	,,	5	,,
25 hoops and 4 angle-bars .	4,189	,,	,,	,,	,,	,,	5	,,	,,	12	,,
47 hoops	5,289	,,	,,	,,	,,	,,	6	,,	,,	6	,,

Thus both circumferential hoops and longitudinal angles contribute towards increasing the ultimate strength. The angles had no

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other lateral support except that given by the mortar. One diagram gives a number of tests of various mixtures differently reinforced, all of which are about the same ultimate strengths. The compression-stress diagrams of these columns show that the richer mixtures, lightly reinforced, are much more rigid than the leaner mixtures with greater reinforcements. This fact has been borne out by the tests as a whole. The hooped columns are decidedly more compressible than the others, and a query naturally arises as to the value of lateral reinforcement as a method of raising the limit of endurance against long-continued or repeated stresses. The moduli of elasticity as determined at successive stages of loading showed that neat cements and rich mortars underwent little change. In lean mixtures, however, the modulus decreased as the load increased, in some cases falling to half its original value. As compressive stresses of over 50,000 lbs. per square inch frequently occurred in the steel reinforcements of columns tested to ultimate strengths, it was concluded that such steel should have an elastic limit of not less than this value. Measurements were also made on the lateral expansion of loaded columns. Adjacent hoops were found working under very different strains. In conclusion the Author states that the tests show that high ultimate strength can be gained by (1) the use of rich mortars or concretes, (2) longitudinal reinforcements, or (3) circumferential reinforcements by hoops or other means. Rigidity of column can be obtained by the use of rich mortars or by longitudinal steel bars. Rigidity of mortar is only obtained by use of rich mixtures. Economy of costs, to gain compressive strengths, within certain limits, will be promoted generally by the plentiful use of cement. The Author states that columns were being tested under long continued loads.

J. M. M.

Steaming Timber before Treating with Preservative.

OCTAVE CHANUTE.

(Railway and Engineering Review, Chicago, 2 March, 1907, pp. 173–4.)

The Author treats briefly the history of the preservation of wood by means of antiseptics, mentioning the methods of Breant, Burnett, Bethel and Pain. In 1857 Messrs. Lege and Fleury-Pironnett patented an apparatus for injecting sulphate of copper by the steaming-vacuum-pressure process. About this time, a commission appointed by the Agricultural Society of Sarth, France, made a report on the results of experiments by Messrs. Lege and Fleury-Pironnett and also on experiments of their own. They stated that the condition most favourable for injection of preservative is obtained by steaming at 212° to 240° F. for ten minutes to three hours according to the kind and state of the wood. This should be followed for ten minutes with as great a vacuum as possible. With creosote, however, steaming is not used in Europe. Within the last

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three years doubts have been cast on the advantages of steaming even for mineral salts. The Author, after experimenting for ten or fifteen years, considers that the question depends entirely on the condition of the wood to be treated. The problem is to replace the sap with some preservative substance. To clear the sap-cells so as to make room for the preservative, some motive force must be produced inside the wood. This may consist of steam generated in the wood by steaming, or of air, heated by steaming, which has replaced the sap in partially-seasoned timber. The Author experimented during 1890–1900 on various timbers in different stages of seasoning, and found that it required eight hours' steaming at 20 lbs. pressure to bring the centre of an 8-inch by 6-inch freshly-cut sleeper to boiling point, at which the watery sap would begin to evaporate. With sleepers seasoned four to six months the Author found that more sap could be extracted by one to three hours' steaming than with fresh-cut sleepers by three to five hours' steaming at 20 lbs. pressure. With fully-seasoned sleepers, *i.e.*, after six to twelve months' seasoning, the steaming in some cases increased the weight of the timber slightly and in others diminished it (well within 2 per cent.). With fully-seasoned timbers it was found that more chloride of zinc could be injected by commencing with the vacuum and dispensing with previous steaming. These results were confirmed by experiments of Mr. S. M. Rowe in 1904. The following practice has grown up at the Author's works:—(1) To refuse to treat fresh-cut timbers, but to put them down to season; (2) To begin the spring season's treating by steaming unless the timber is of the previous year's cutting; (3) To omit steaming in the summer and autumn when the timber proves to be well seasoned.

J. M. M.

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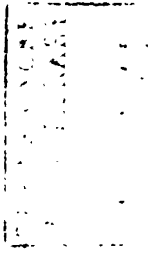

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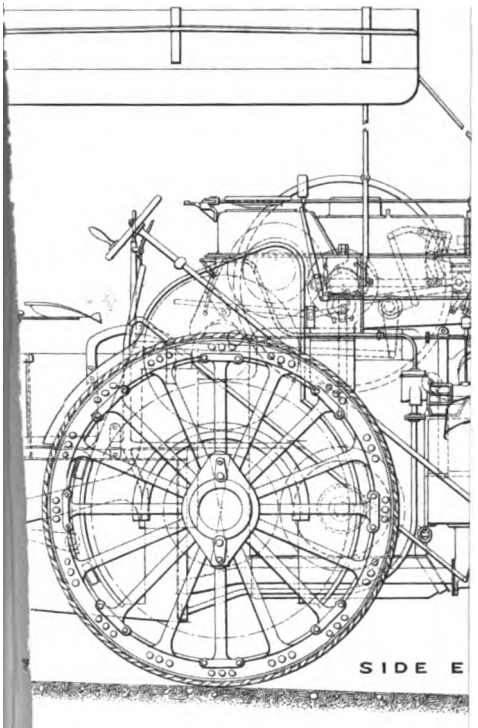

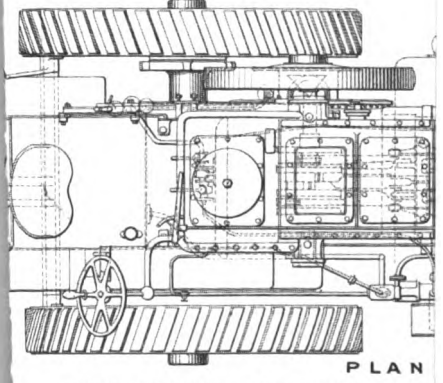

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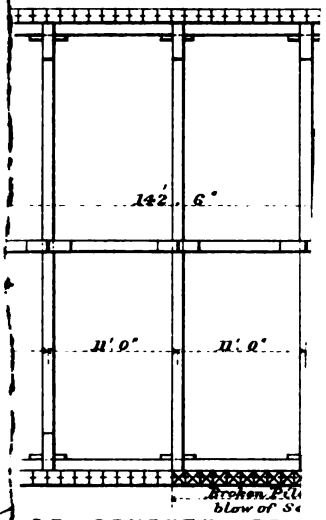

OF SEVENTH FRA

IN A.

DOLPHINS C.

T. H.

DOLPHIN B.

Floating boom.

-34
to-36

W. C.

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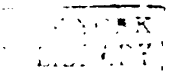

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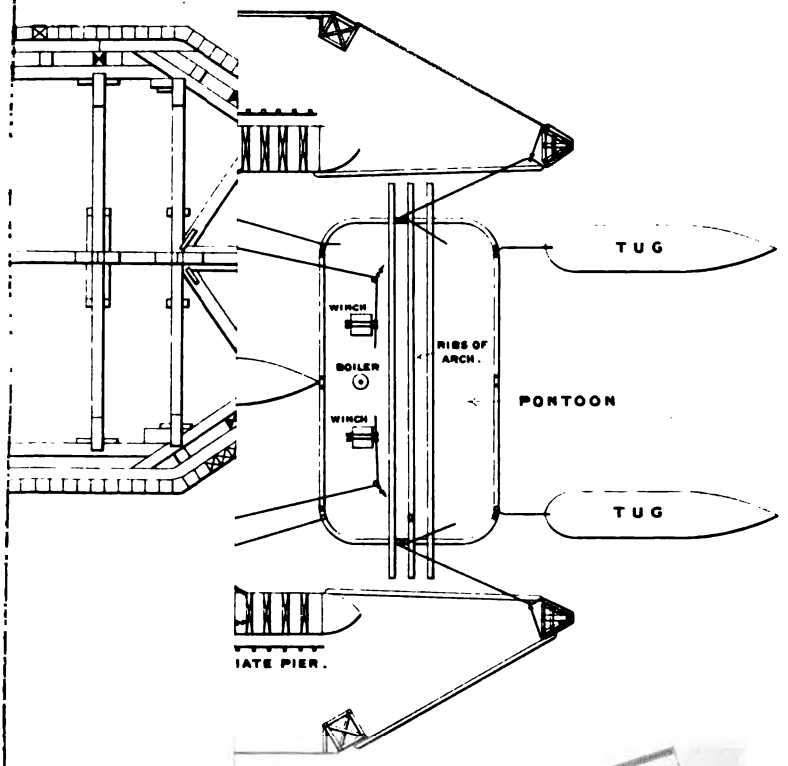

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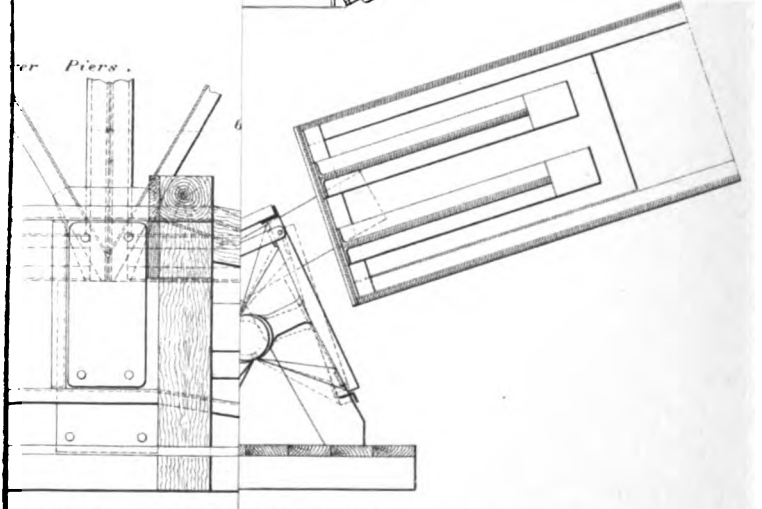

TRUCTURE OF PIER. EVATION
of Ribs in Position teel Castings while the Arched
oated in position.

THOS KELL & SON, LITH. 90 KING ST. CHEAPSIDE.

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Figs:

I N G.

T I O N

C A S T - I R O N

Figs: 7.

S I D E

E L E V A T I O N

P L A N

O N B R

P A N S I O N B E D -

E N D E L E V A T I O N

THOS KELL & SON, LITH. 40 KING ST. COVENT GARDEN.

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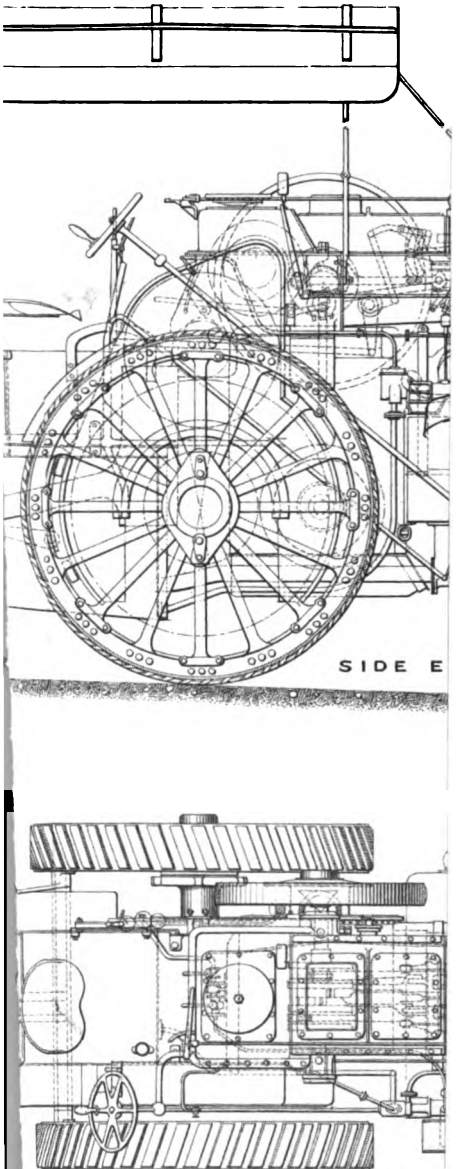
Figs. 10.



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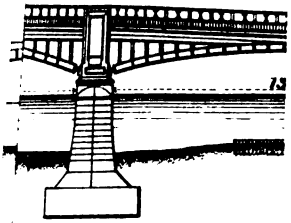

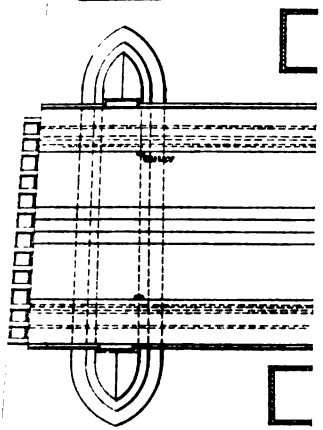

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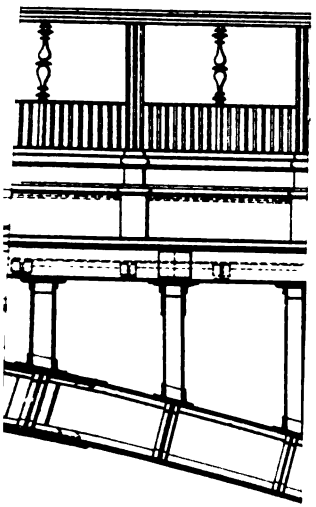

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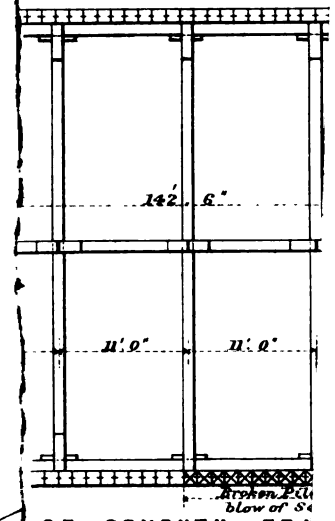

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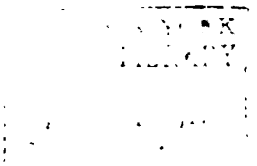

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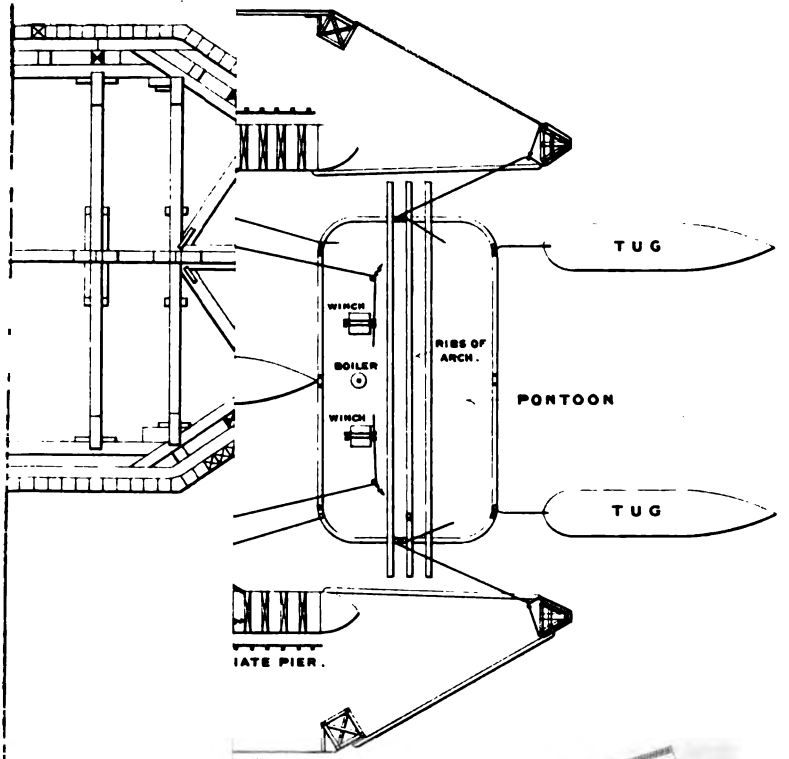

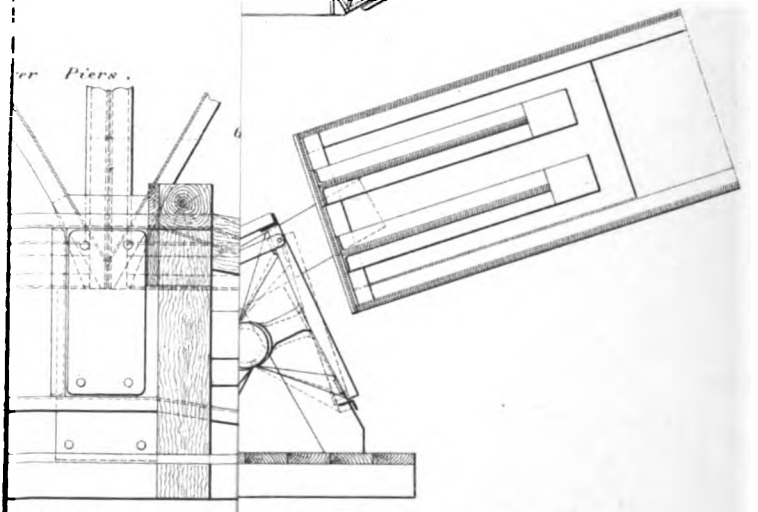

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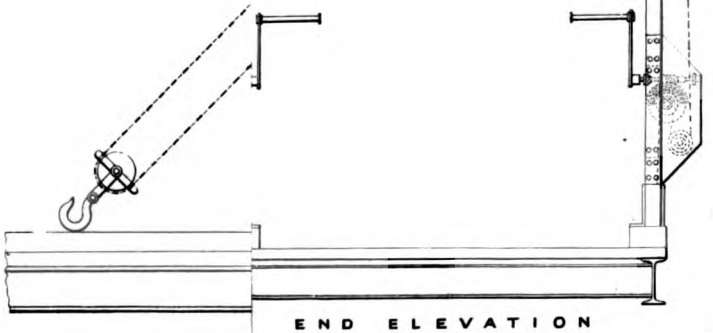
PLAN

BR PANSION BED-



END ELEVATION

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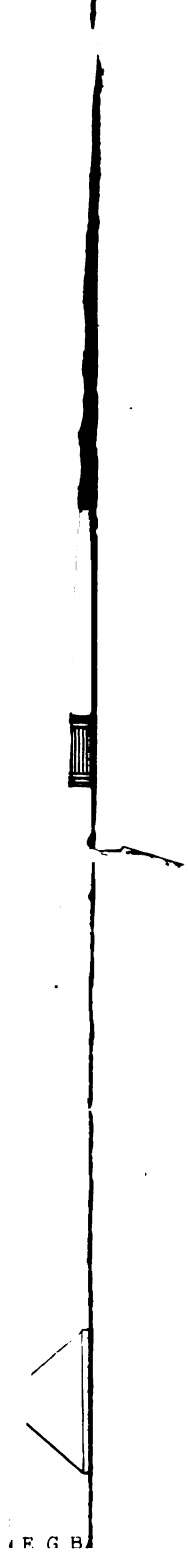

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